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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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No. 612

SPINNING CHARACTERISTICS OF WINGS

III - A RECTANGULAR AND A TAPERED CLARK Y MONOPLANE WING WITH ROUNDED TIPS

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SUMMARY

An investigation was made to determine the spinning characteristics of Clark Y monoplane wings with different plan forms. A rectangular wing and a wing tapered 5:2, both with rounded tips, were tested on the N.A.C.A. spinning balance in the 5-foot vertical wind tunnel.

The aerodynamic characteristics of the models and a prediction of the angles of sideslip for steady spins are given. Also included is an estimate of the yawing moment that must be furnished by the parts of the airplane to balance the inertia couples and wing yawing moment for spinning equilibrium. The effects on the spin of changes in plan form and of variations of some of the important parameters are discussed and the results are compared with those for a rectangular wing with square tips.

It is concluded that for a conventional monoplane using Clark Y wings: The sideslip will be algebraically larger for the wing with the rounded tip than for the wing with the square tip and will be largest for the tapered wing; the effect of plan form on the spin will vary with the type of airplane; and the provision of a yawing-moment coefficient of -0.025 (i.e., opposing the spin) by the tail, fuselage, and interference effects will insure against the attainment of equilibrium in a steady spin for any of the plan forms tested and for any of the parameters used in the analysis.

INTRODUCTION

In order to provide the necessary aerodynamic data for predicting airplane spinning characteristics from the design features, the N.A.C.A. is conducting an extensive investigation to determine the aerodynamic characteristics of airplane models and parts of airplane models in spinning attitudes.

The investigation to determine the spinning characteristics of wings, in which the N.A.C.A. spinning balance was used, has included variations in airfoil section, plan form, and tip shape of monoplane wings and in stagger for biplane cellules. The first series of tests, made of a rectangular Clark Y monoplane wing with square tips, is reported in reference 1 and the second series, made of a rectangular Clark Y biplane cellule, is reported in reference 2; the effects of changes in airfoil section and in stagger are to be published later. These reports give analyses of the data for predicting the probable effects on the steady spin of some of the important parameters for normal airplanes using such wing combinations.

This report gives the aerodynamic characteristics in spinning attitudes of a rectangular and of a 5:2 tapered Clark Y monoplane wing with rounded tips. Data for the square-tip wing previously tested are included for comparison. The discussion of the data is based on the method of analysis given in reference 1.

APPARATUS AND MODELS

The tests were made on the spinning balance in the N.A.C.A. 5-foot vertical wind tunnel. The tunnel is described in reference 3 and the 6-component balance in reference 4.

The Clark Y wings are made of laminated mahogany and are of aspect ratio 6. One wing is rectangular in plan form; the other is tapered 5:2. Both wings have rounded tips. For the rectangular wing the tip plan form is composed of two quadrants of similar ellipses; for the tapered wing the ordinates of the two quadrants of similar ellipses have been expanded in proportion to the taper. (The ellipses are based on a chord length which is the root chord multiplied by the taper ratio.) The Clark Y profile is maintained to the ends of the wings and the maximum upper-surface section ordinates are in one plane. This tip shape, as shown in figures 1 and 2, has been designated the "Army" tip. Figures 3 and 4 show the wings mounted on the balance.

TESTS

In order to cover the probable spinning range, tests were made at 30°, 40°, 50°, 60°, and 70° angle of attack. At each angle of attack tests were made with sideslip angles of 10°, 5°, 0°, -5°, and -10°. At each angle of attack α and at each angle of sideslip β, tests were made with values of $\Omega b/2V$ of 0.25, 0.50, 0.75, and 1.00. The angles of attack and angles of sideslip were measured in the plane of symmetry at the quarter-chord point of the wing, which was also the center of rotation for all tests. So that the results might be consistent, repeat tests were made for each condition until individual balance readings were found to agree within a specified limit or until a sufficient number of readings had been made to give a fair average. In each case an average of the individual measurements was used to compute the coefficients.

The tunnel air speed was 70 feet per second for tests with $\frac{\Omega b}{2V}$ = 0.25 and 0.50 and 60 and 45 feet per second for $\frac{\Omega b}{2V}$ = 0.75 and 1,00, respectively. The Reynolds Numbers of the tests were about 210,000 for the highest air speed and 140,000 for the lowest air speed. Previous tests showed no appreciable change in scale effects for this range.

RESULTS AND DISCUSSION

The data were converted to coefficient form by the following relations:

$$C_X = \frac{X}{qS} \qquad C_Y = \frac{Y}{qS} \qquad C_Z = \frac{Z}{qS}$$

$$C_l = \frac{L}{qbS} \qquad C_m = \frac{M}{qbS} \qquad C_n = \frac{N}{qbS}$$

All coefficients are standard N.A.C.A. coefficients except C_m, which is based on the span instead of the chord of the wing, and it may be converted to the standard coefficient by multiplying by 6. All coefficients are given with the conventional signs for right spins.

The values of the longitudinal-force coefficient $C_{X''}$ (earth axes) are plotted against angle of attack in figure 5; sample curves of $C_{X''}$ against β and $\Omega b/2V$ are given in figure 6. Similar curves are given for C_Z, C_l, C_m, and C_n in the body system of axes in figures 7 to 14. The values of C_X and C_Y are not given because they are small and of no particular importance.

The data given are believed to be correct to within the following limits:

$C_{X''}$, ± 0.02	C_Z, ± 0.02	C_m, ± 0.002
C_l, ± 0.001	C_n, ± 0.001	

No corrections have been made for the effects of the jet boundary, scale, or interference of the balance.

Corresponding curves for the three wings have the same general shape (figs. 5 to 14 and, reference 1, figs. 4 to 8).

The values of $C_{X''}$ (figs. 5 and 6) are slightly larger for the wing with the rounded tip than they are for the wing with the square tip, the effect diminishing with increasing angle of attack. The effect of taper is negligible.

The absolute values of C_Z (figs. 7 and 8) are slightly larger for the wing with the rounded tip than for the wing with the square tip and are largest for the tapered wing. This effect is largest at the lower angles of attack and becomes negligible at the higher angles.

The values of the rolling-moment coefficient C_l when $\frac{\Omega b}{2V} = 0.25$ are about the same for all wings tested (figs. 9 and 10). As the value of $\Omega b/2V$ is increased, the values of C_l are algebraically greater for the wing with the rounded tip than for the wing with the square tip and are largest for the tapered wing.

The values of the pitching-moment coefficient C_m are about the same for the tapered and rounded-tip wings. The slope of the curves of pitching moment against angle of attack for the rectangular wing is more negative than that of the other two wings and this difference becomes more pronounced as the value of $\Omega b/2V$ increases (figs. 11 and 12 and reference 1, fig. 6).

The values of the yawing-moment coefficient C_n (figs. 13 and 14) are small and are nearly the same for all three wings.

The fact that the curves for the rounded tip and tapered wings are more regular than those given for the rectangular wing in reference 1 is probably due more to the greater accuracy of results, as explained in reference 4, than to plan-form effects.

ANALYSIS

The data were analyzed to show the effects of some of the important parameters on the spinning characteristics of an airplane using similar wings. The method of analysis with the assumptions used and the errors involved is given in reference 1. As in references 1 and 2, values of scale-effect corrections of 0.02 for C_l and of 0.006 for C_n have been used in the analysis.

Parameters.- The characteristics of the particular airplane determine the values of wing loading, aspect ratio, radii of gyration, and pitching moments. Values of those variables, which were used in references 1 and 2, were also used in this analysis for consistency of results, although present airplanes are not all included within this range. The chosen means of those values gave the following parameters:

Relative density of airplane to air $(W/g\rho bS)$, $\mu = 5$

Pitching-moment inertia parameter,

$$\frac{b^2}{{k_Z}^2 - {k_X}^2} = 80$$

Rolling- and yawing-moment inertia parameter,

$$\frac{{k_Z}^2 - {k_Y}^2}{{k_Z}^2 - {k_X}^2} = 1.0$$

Slope of pitching-moment curve, $\frac{-C_m}{\alpha - 20^\circ} = 0.0020$

Lift coefficient, $C_L = C_{X''}$

Each of the parameters was varied, one at a time, while all of the others were kept at the mean values, except C_L, which was set equal to $C_{X''}$ for all cases. The values of the parameters used are:

$\mu = 2.5$, 5.0, 7.5, and 10.0.

$$\frac{b^2}{k_Z^2 - k_X^2} = 60,\ 80,\ 100,\ \text{and } 120$$

$$\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 0.5,\ 1.0,\ 1.5,\ \text{and } 2.0.$$

$$\frac{-C_m}{\alpha - 20^\circ} = 0.0010,\ 0.0015,\ 0.0020,\ 0.0025,\ \text{and } 0.0030.$$

The variations in μ include the range for airplanes that are normally spun.

The values of $\frac{b^2}{(k_Z^2 - k_X^2)}$ and $\frac{(k_Z^2 - k_Y^2)}{(k_Z^2 - k_X^2)}$ cover the range for 11 airplanes given in reference 5. These parameters may be written as $\frac{Wb^2}{g(C - A)}$ and $\frac{(C - B)}{(C - A)}$, respectively, where

$A = mk_X^2$, the moment of inertia about the X axis.

$B = mk_Y^2$, the moment of inertia about the Y axis.

$C = mk_Z^2$, the moment of inertia about the Z axis.

Discussion of results of analysis.- The angles of sideslip at which the pitching and rolling moments balance in the spin and the yawing moment that must be furnished by the other parts of the airplane to balance the inertia couples and the wing yawing moments are plotted against the parameters in figures 15 to 22. Corresponding figures for the wing with square tips are given in reference 1 (figs. 19 to 28). Negative values of C_n required show the amount of yawing moment that must be supplied to balance the resultant aiding moment given by the wings and the inertia couples. It is obvious that in order to insure against a dangerous spin an additional opposing moment must be supplied as a margin of safety.

Increasing $-C_m/(\alpha - 20^\circ)$, that is, increasing the diving moment at any angle of attack, algebraically decreases the sideslip β. (See fig. 15.) Generally β increases algebraically and the slope of the curves becomes less as the wing tips are rounded and the plan form tapered. Increasing $-C_m/(\alpha - 20^\circ)$ slightly, increases the yawing moment aiding the spin (makes C_n required more negative in a right spin). (See fig. 16.) A comparison of the values of C_n required by the different plan forms shows that the plan-form effects are dependent upon the angle of attack. At 30° angle of attack the values for all wings are about the same. At 40° the values of C_n required are about the same for the rounded tip and tapered wings (fig. 16) while the values for the rectangular wing are more negative (reference 1, fig. 24). At angles of attack of 50° and above, and especially for 70°, the values of C_n required are least negative for the square-tip wing.

Increasing the pitching-moment inertia parameter is equivalent to moving weights in the fuselage and wings toward the center of gravity so as to decrease A, B, and C while keeping A and B equal. Variations in this parameter give approximately the same changes in sideslip and yawing moment required as variations in $-C_m/(\alpha - 20^\circ)$. (See figs. 17 and 18.)

Increasing the rolling- and yawing-moment inertia parameter, $\frac{(k_Z^2 - k_Y^2)}{(k_Z^2 - k_X^2)}$ means moving the weights in the wing away from the center of gravity. As this parameter increases, the sideslip for the rounded-tip and tapered wings decreases algebraically (fig. 19); whereas, for the square-tip wing, the sideslip decreases at 30° and 40° angle of attack but increases at and above 50° (reference 1, fig. 23). At the higher angles of attack the slopes of these curves for the square-tip wing are of different sign than for the rounded-tip wing and the slopes are most negative for the tapered wing. The yawing moment required decreases algebraically as $\dfrac{(k_Z^2 - k_Y^2)}{(k_Z^2 - k_X^2)}$ is increased (fig. 20) except for the square-tip wing at 50°, 60°, and 70° angle of attack (reference 1, fig. 28).

Increasing the relative density μ generally increases the sideslip (fig. 21). The slope of the curves is less for the rounded-tip wing (fig. 21(a)) than it is for the square-tip wing (reference 1, fig. 20) and it is least for the tapered wing (fig. 21(b)). Increasing μ generally algebraically increases the C_n required (fig. 22). Rounding the wing tips and tapering the wing generally algebraically decreases the C_n required.

Probable effects of scale and of interference on the results of the analysis.- The effects of interference and a more extensive study of the effects of scale are reported in reference 4. The effect of scale on C_l was found to be about the same as that used in reference 1 and the interference effects on C_l due to testing the wing alone were small.

The scale effect on C_n of the complete model was found to vary with sideslip. Below a value of 5° inward sideslip, however, the variation with β is small, the average value of the difference caused by scale effect being 0.006. The values of C_n for the airplane wing were computed from results of tests made with the airplane in flight. These values were compared with those of the model wings tested alone and a difference of 0.013 was indicated. Since the airplane wing was on the airplane when the measurements were made and the model wings were tested alone, the value of 0.013 is a combination of scale and interference effects. The interference effects are large but corrections are impossible because of lack of data. Any correction made to C_n required moves all the curves of C_n required up or down on the scale without much change in their relative positions. Therefore, the comparisons between the three plan forms of wings given in this report would not be appreciably affected by using another correction for C_n.

Prediction of spinning characteristics of an airplane from the analysis.- The spinning characteristics of an airplane using any of the three wings will be largely dependent upon the aerodynamic yawing-moment characteristics of the particular airplane. The aerodynamic yawing moments for a particular airplane depend upon: the size and shape of the fuselage and tail surfaces; the location of the horizontal tail surfaces with respect to the fuselage, fin, and rudder; the amount of fin area ahead of the center of gravity; the interference effects between the wings and the rest of the airplane; and the limits of control movements. Data on some of these effects are reported in reference 4 and in references 6 to 14.

The geometry of the spin indicates that the vertical tail surfaces should become more effective in producing a yawing moment opposing the spin as the rate of rotation increases and the outward sideslip becomes larger. Another factor in the effects of sideslip on the yawing moment in the spin is the static stability of the airplane in yaw in the attitude in question. (See reference 13.) If the airplane is statically stable, outward sideslip will give an increment of yawing moment opposing the spin and, if it is statically unstable, inward sideslip will give an increment of yawing moment opposing the spin. In other words, if inward sideslip is necessary for spinning equilibrium, considerable fin area ahead of the center of gravity reduces the likelihood of attaining a dangerous spin.

If the effects of sideslip on the yawing moment required are neglected, an airplane with the tapered wing will, except at 30° angle of attack, have the smallest yawing moment aiding the spin when the weight is concentrated in the fuselage. When there are heavy weights in the wings, the rectangular wing will usually give the smallest aiding moment. At 70° angle of attack the square-tip wing will generally give smaller yawing moments aiding the spin than either the rounded-tip or tapered wing; i.e., an airplane with a Clark Y square-tip wing will be less likely to spin flat, above 60° angle of attack, than one with a rounded-tip or tapered wing. There is an exception when $\frac{(k_Z^2 - k_Y^2)}{(k_Z^2 - k_X^2)} < 0.7$, the tapered wing then being the least likely to give a flat spin.

The effect of sideslip makes necessary a study to determine a favorable combination of variables for a given airplane because, if the design does not allow for favorable combinations, a dangerously spinning airplane is liable to be the result. Sideslip usually gives counteracting effects on the yawing moments of the various parts of the airplane, the net effect determining the possibility of attaining spinning equilibrium. If allowance is made for the effects of sideslip, the results indicate that the parameters which would tend to make attainment of equilibrium in a steady spin more difficult are:

<u>Tapered wing</u>:

Weights concentrated in the fuselage $\left(\frac{(k_Z^2 - k_Y^2)}{(k_Z^2 - k_X^2)} < 1\right)$.

Small diving moments (center of gravity well back, small elevator and stabilizer, and large elevator-up deflections).

Low wing loadings and high aspect ratio $\left(\text{small values of} \quad \mu = \frac{W}{g\rho Sb}\right)$.

<u>Square-tip wing</u>:

Weights distributed along the wings $\left(\frac{(k_Z^2 - k_Y^2)}{(k_Z^2 - k_X^2)} > 1\right)$.

Small fin area ahead of the center of gravity (large static stability).

Large diving moments (center of gravity well forward, large elevator and stabilizer, and small elevator-up deflection).

High wing loadings and low aspect ratio $\left(\text{large values of} \quad \mu = \frac{W}{g\rho Sb}\right)$.

<u>Rounded-tip wing</u>:

The parameters for which this wing would be best are usually between the square-tip wing and the tapered wing.

CONCLUSIONS

If it is assumed that the added corrections to the rolling- and yawing-moment coefficients are of the right order of magnitude, the following conclusions are indicated by the analysis presented for a conventional monoplane with a Clark Y wing.

1. The value of the yawing-moment coefficient required from the fuselage, tail, and interference effects for steady spinning equilibrium is small and nearly always negative (opposing the spin) throughout the angle-of-attack range investigated. It appears that the spinning attitude of the airplane will depend mostly upon details of shape, size, and arrangement of fuselage and tail.

2. The maximum yawing-moment coefficient that must be supplied by parts of the airplane other than the wings to insure against attainment of equilibrium in a steady spin is -0.025 (opposing the rotation).

3. The sideslip will be algebraically larger (less outward) for the wing with the rounded tip than for the wing with the square tip, and it will be the largest for the tapered wing.

4. The only general superiority of one plan form over another of those tested is in the case of weight distribution. The plan form least likely to result in spinning equilibrium is the tapered wing, if the weight of the airplane is concentrated in the fuselage $\left(\frac{(k_Z^2 - k_Y^2)}{(k_Z^2 - k_X^2)} < 1\right)$; and the rectangular wing with the square tip, if the weight is distributed along the wings.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 30, 1937.

REFERENCES

1. Bamber, M. J., and Zimmerman, C. H.: Spinning Characteristics of Wings. I - Rectangular Clark Y Monoplane Wing. T.R. No. 519, N.A.C.A., 1935.

2. Bamber, M. J.: Spinning Characteristics of Wings. II - Rectangular Clark Y Biplane Cellule: 25 Percent Stagger; 0° Decalage; Gap/Chord 1.0. T.N. No. 526, N.A.C.A., 1935.

3. Wenzinger, Carl J., and Harris, Thomas A.: The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 387, N.A.C.A., 1931.

4. Bamber, M. J., and House, R. O.: Spinning Characteristics of the XN2Y-1 Airplane Obtained from the Spinning Balance and Compared with Results from the Spinning Tunnel and from Flight Tests. T.R. No. 607, N.A.C.A., 1937.

5. Miller, Marvel P., and Soulé, Hartley A.: Moments of Inertia of Several Airplanes. T.N. No. 375, N.A.C.A., 1931.

6. Irving, H. B., Batson, A. S., and Warsap, J. H.: The Contribution of the Body and Tail of an Aeroplane to the Yawing Moment in a Spin. R. & M. No. 1689, British A.R.C., 1936.

7. Stephens, A. V.: Das Trudeln von Flugzeugen. Luftfahrtforschung, Bd. 11, Nr. 5, 25 Okt. 1934, S. 140-149.

8. Irving, H. B.: A Simplified Presentation of the Subject of the Spinning of Aeroplanes. R. & M. No. 1535, British A.R.C., 1933.

9. Stephens, A. V., and Francis, R. H.: Model Spinning Tests of an Interceptor Fighter. R. & M. No. 1578, British A.R.C., 1934.

10. Irving, H. B., and Stephens, A. V.: Safety in Spinning. R.A.S. Jour., vol. XXXVI, no. 255, March 1932, pp. 145-204.

11. Stephens, A. V.: Recent Research on Spinning. R.A.S. Jour., vol. XXXVII, no. 275, Nov. 1933, pp. 944-955.

12. Bamber, M. J., and Zimmerman, C. H.: Effect of Stabilizer Location upon Pitching and Yawing Moments in Spins as Shown by Tests with the Spinning Balance. T.N. No. 474, N.A.C.A., 1933.

13. Scudder, N. F.: The Forces and Moments Acting on Parts of the XN2Y-1 Airplane during Spins. T.R. No. 559, N.A.C.A., 1936.

14. Zimmerman, C. H.: Effect of Changes in Tail Arrangement upon the Spinning of a Low-Wing Monoplane Model. T.N. No. 570, N.A.C.A., 1936.

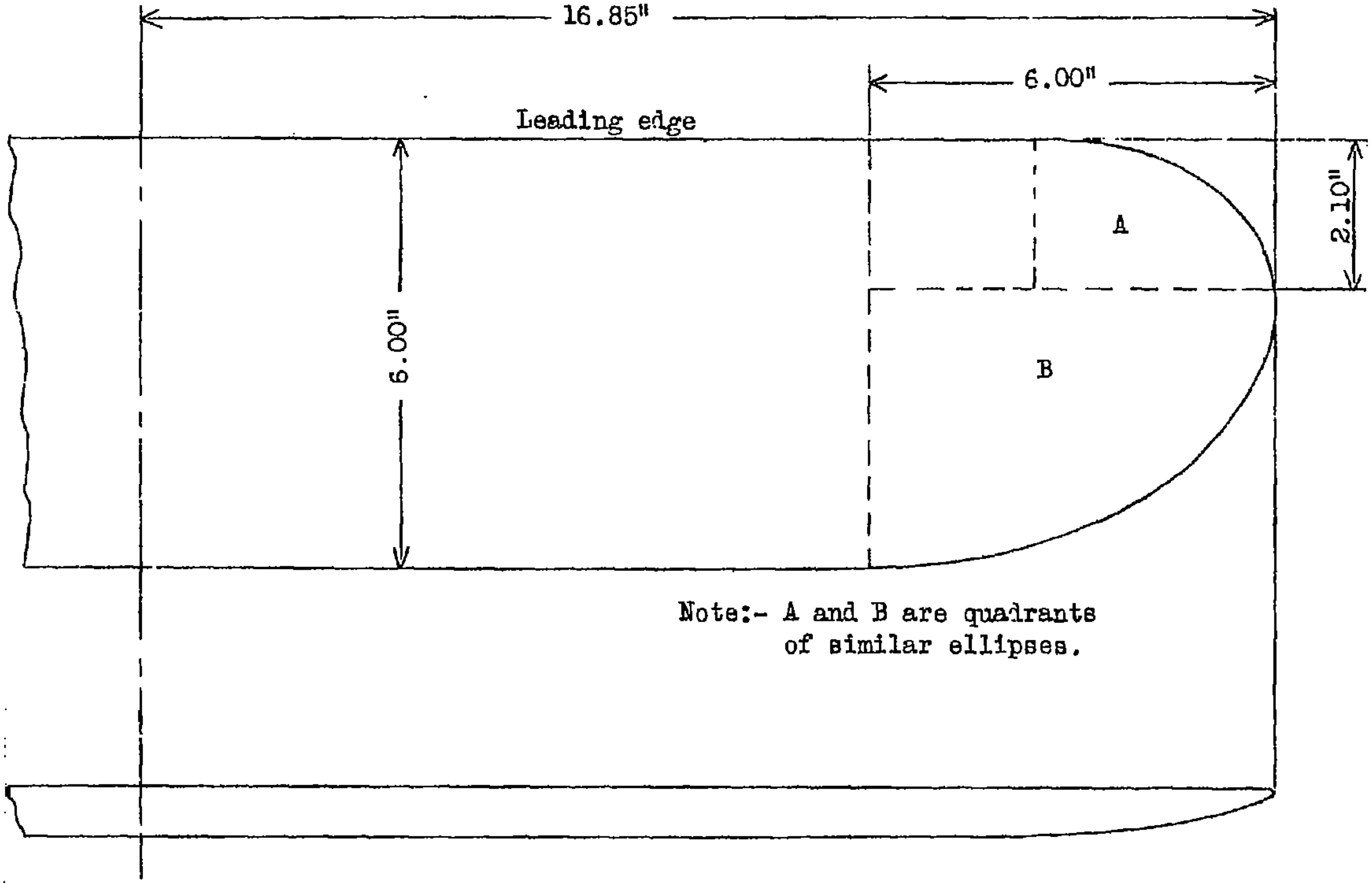


Figure 1.- The rectangular Clark Y wing with rounded tips.

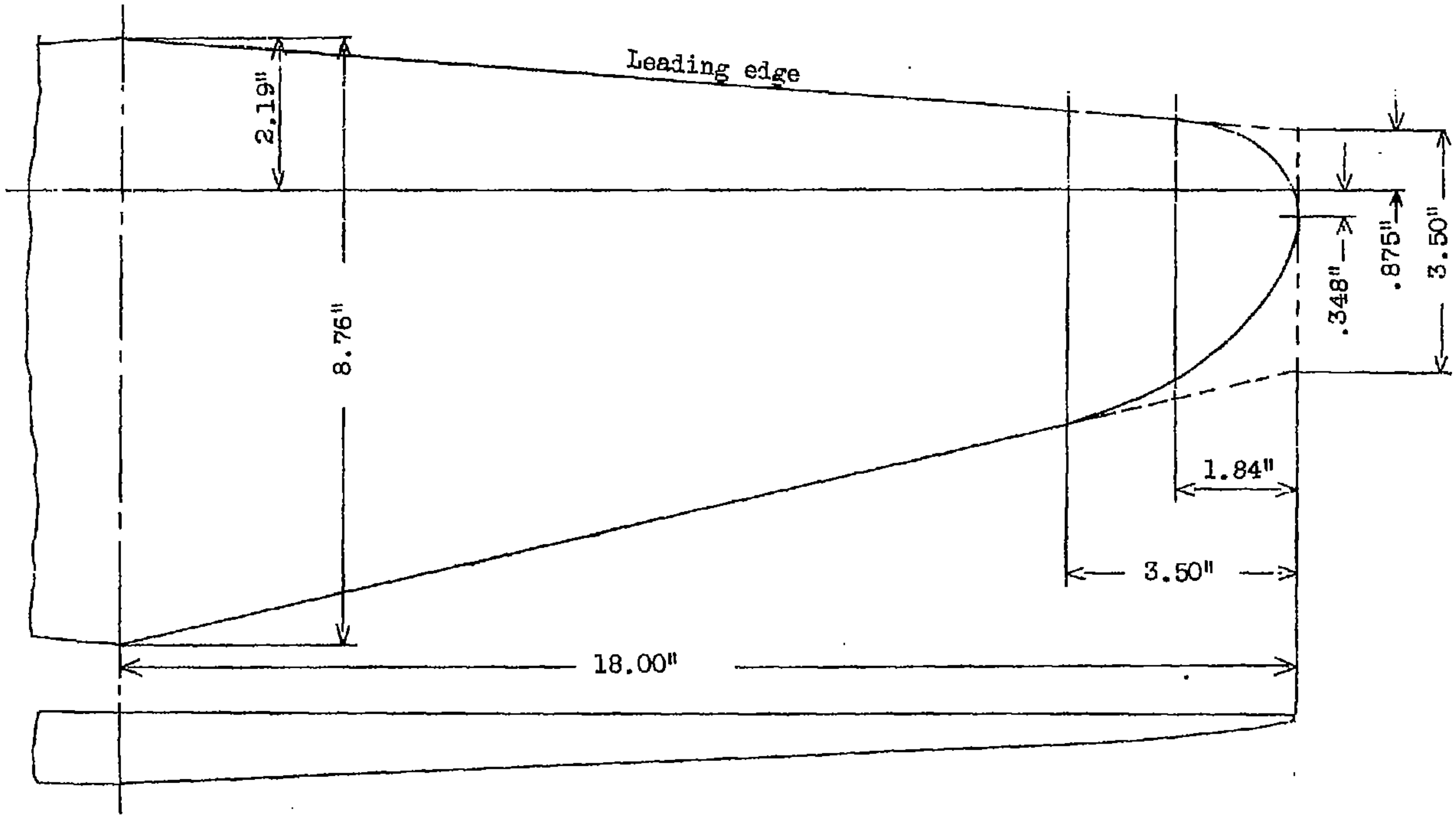


Figure 2.- The 5:2 tapered Clark Y wing with rounded tips.

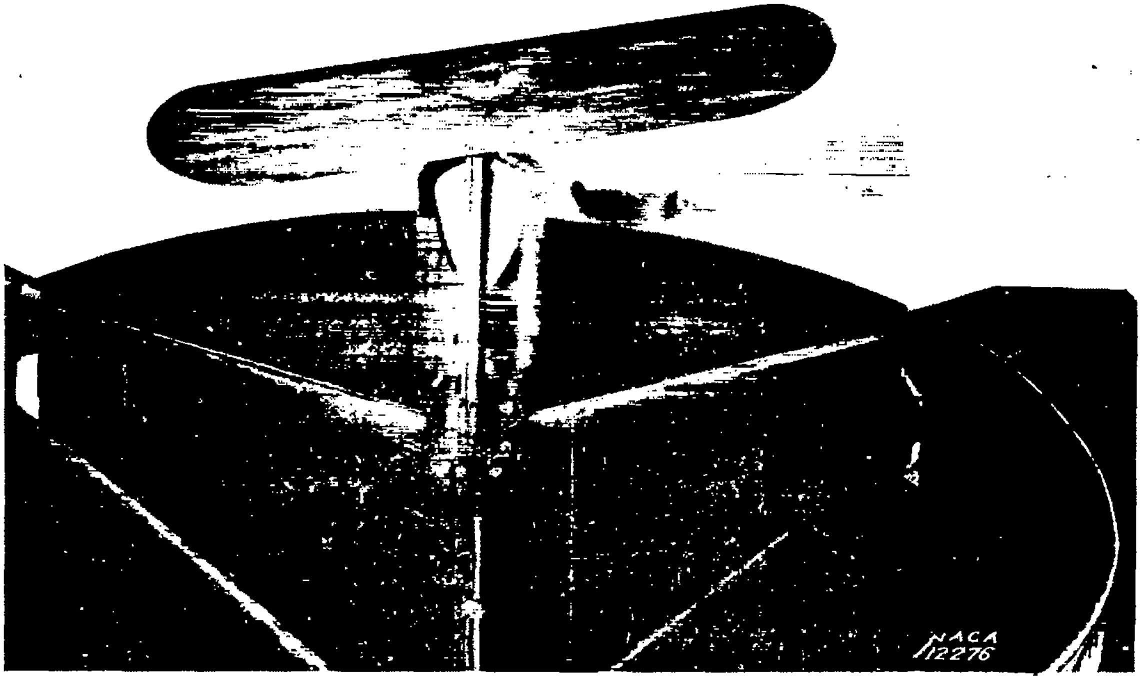


Figure 3.- The rectangular Clark Y wing with rounded tips mounted on the spinning balance.

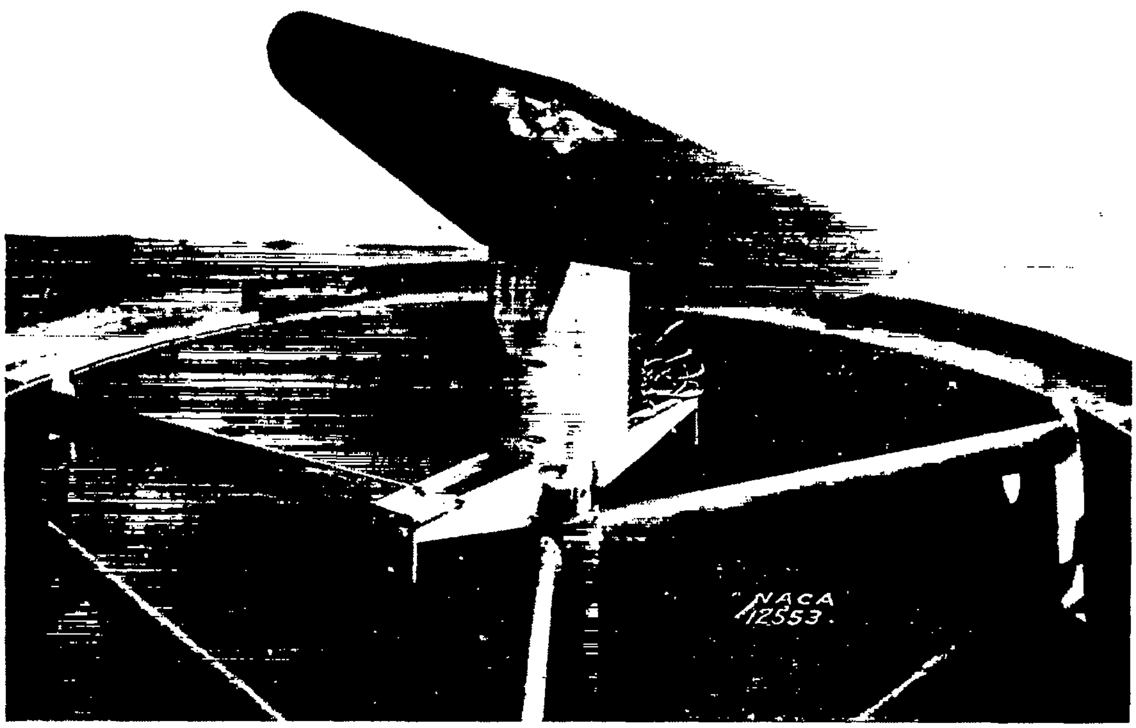


Figure 4.- The 5:2 tapered Clark Y wing with rounded tips mounted on the spinning balance.

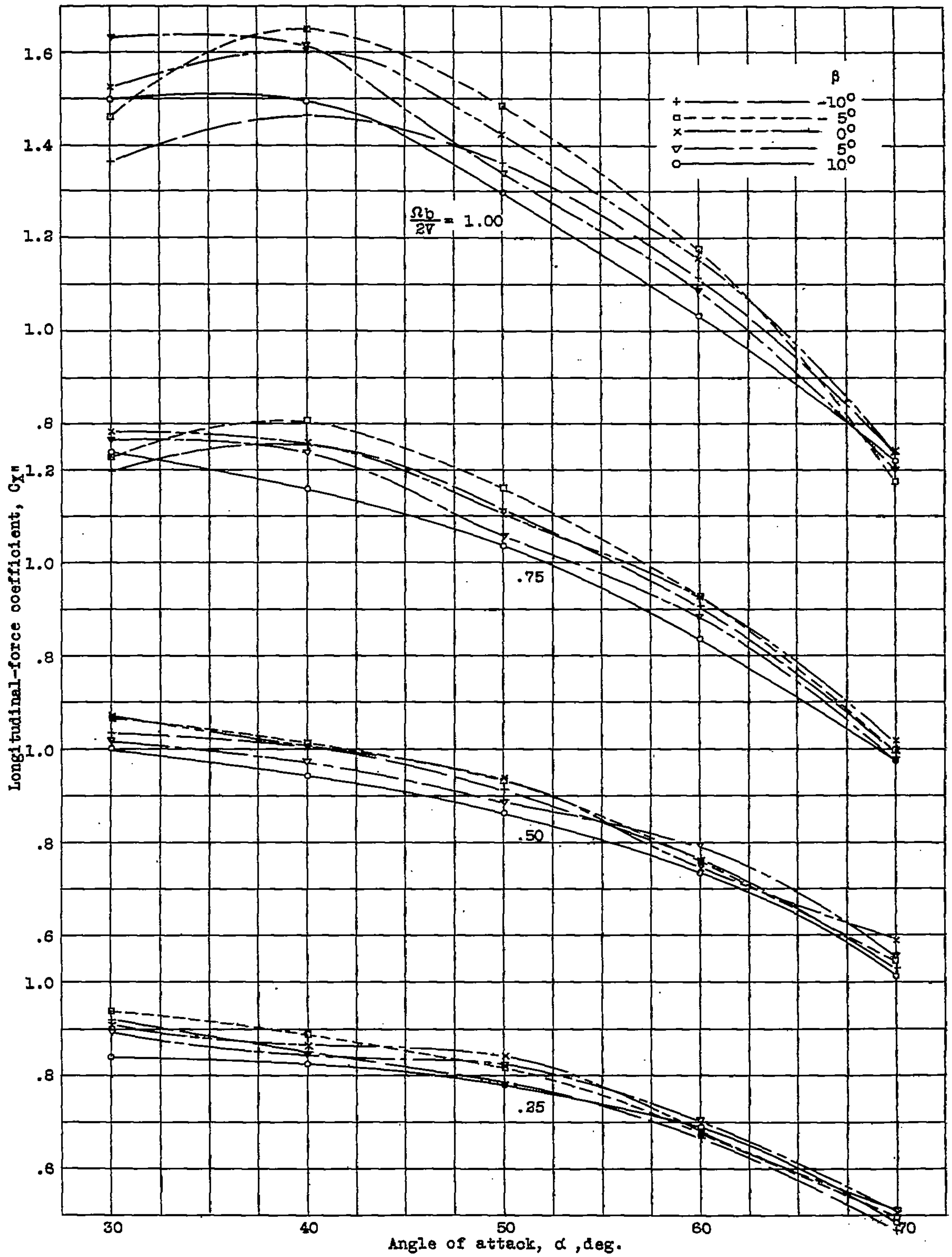


Figure 5a.- Variation of longitudinal-force coefficient C_X" (earth axes) with angle of attack; rectangular wing, rounded tips.

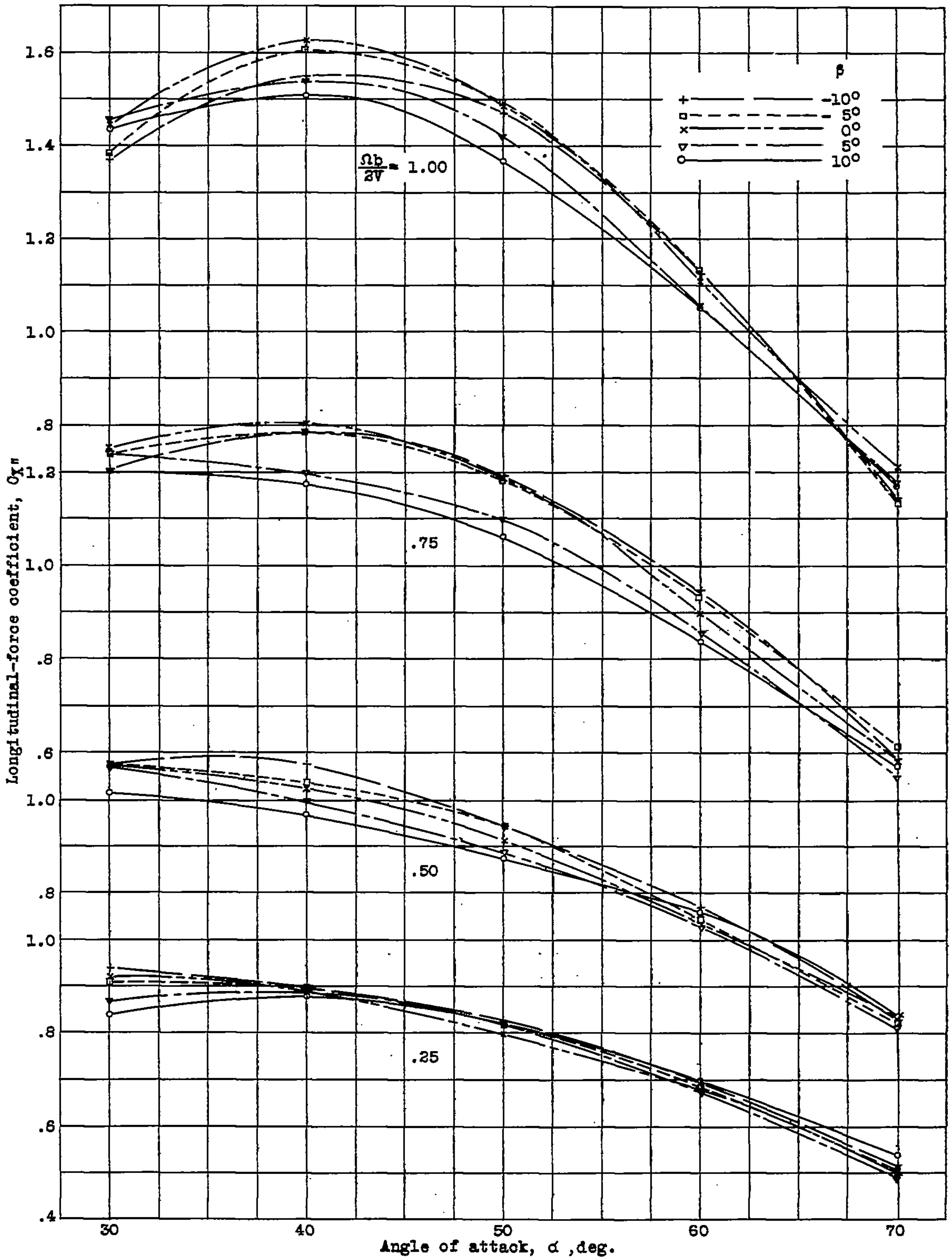


Figure 5b.- Variation of longitudinal-force coefficient C_X" (earth axes) with angle of attack; 5:2 tapered wing, rounded tips.

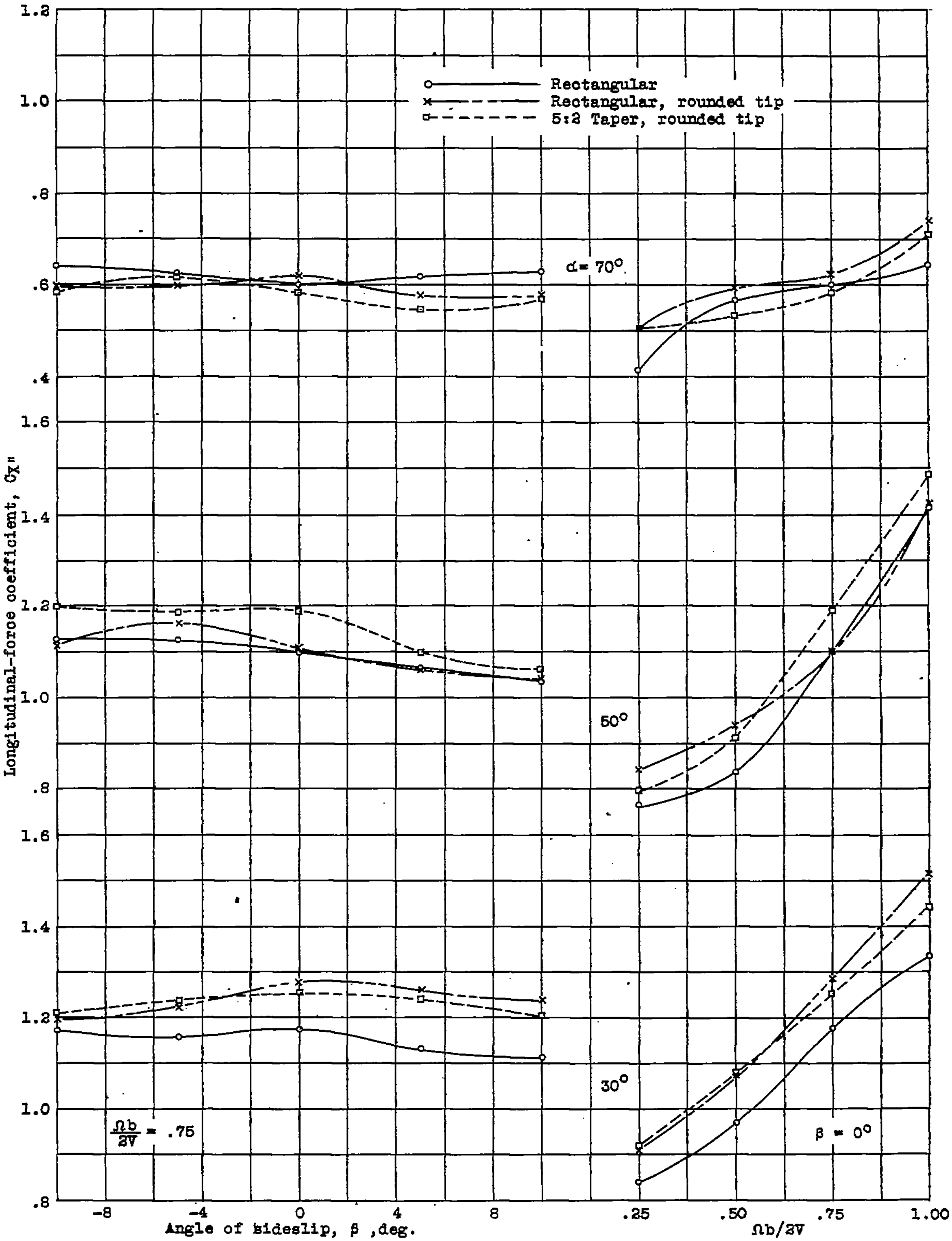


Figure 6.- Variation of longitudinal-force coefficient $C_{X''}$ (earth axes) with angle of sideslip and with Ωb/2V

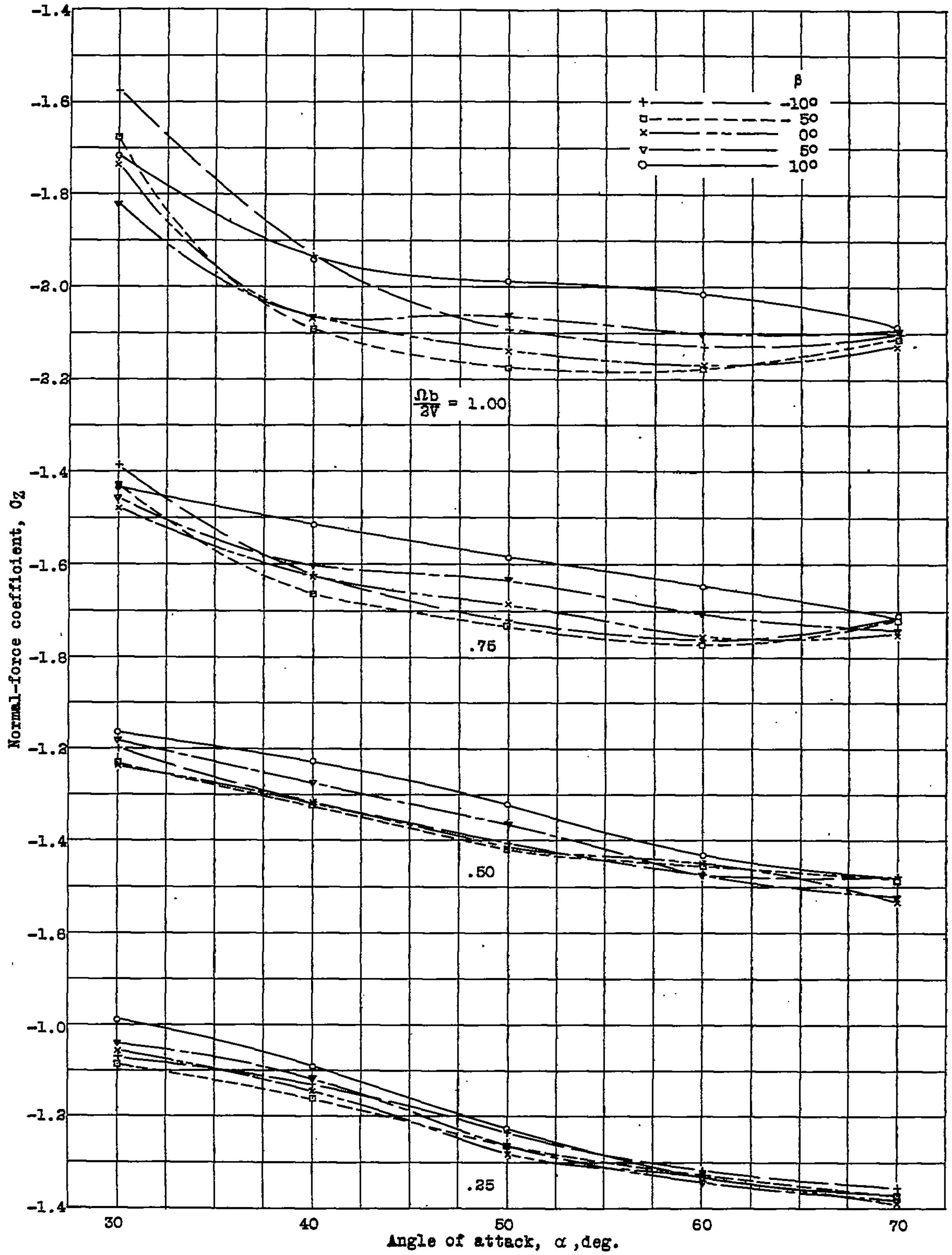


Figure 7a.- Variation of normal-force coefficient C_Z (body axes) with angle of attack; rectangular wing, rounded tips.

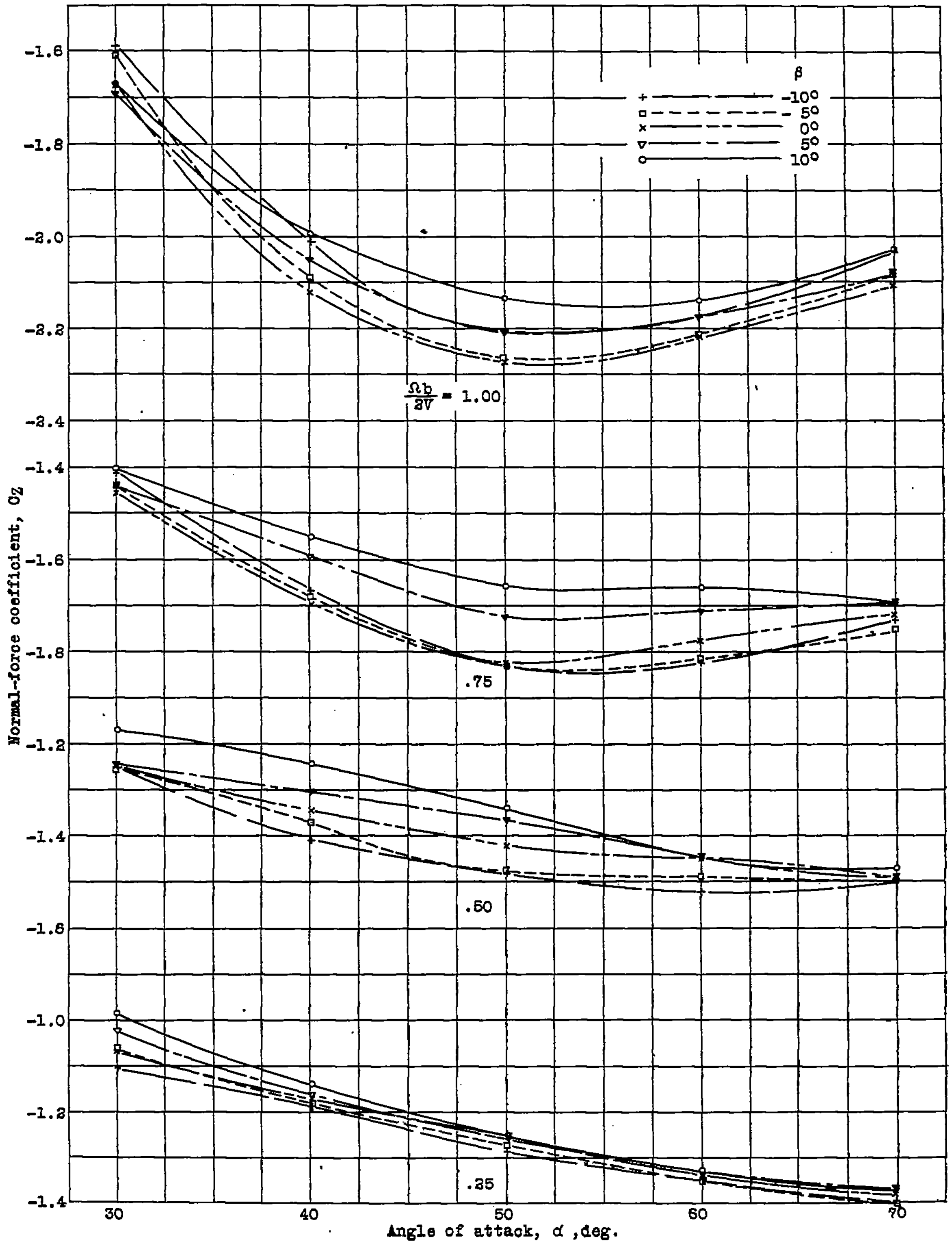


Figure 7b.- Variation of normal-force coefficient C_Z (body axes) with angle of attack; 5:2 tapered wing, rounded tips.

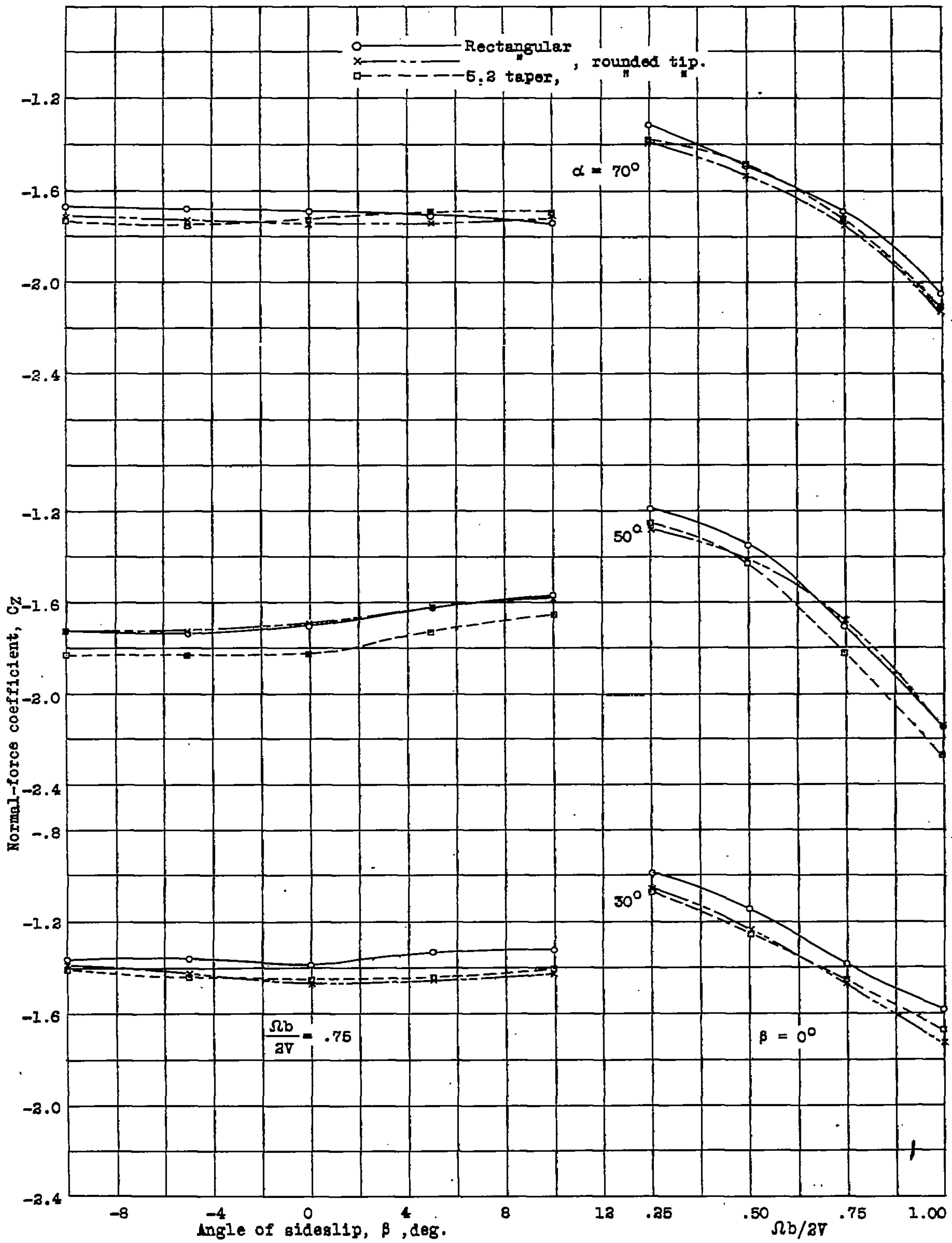


Figure 8.- Variation of normal-force coefficient C_Z(body axes) with angle of sideslip and $\Omega b/2V$.

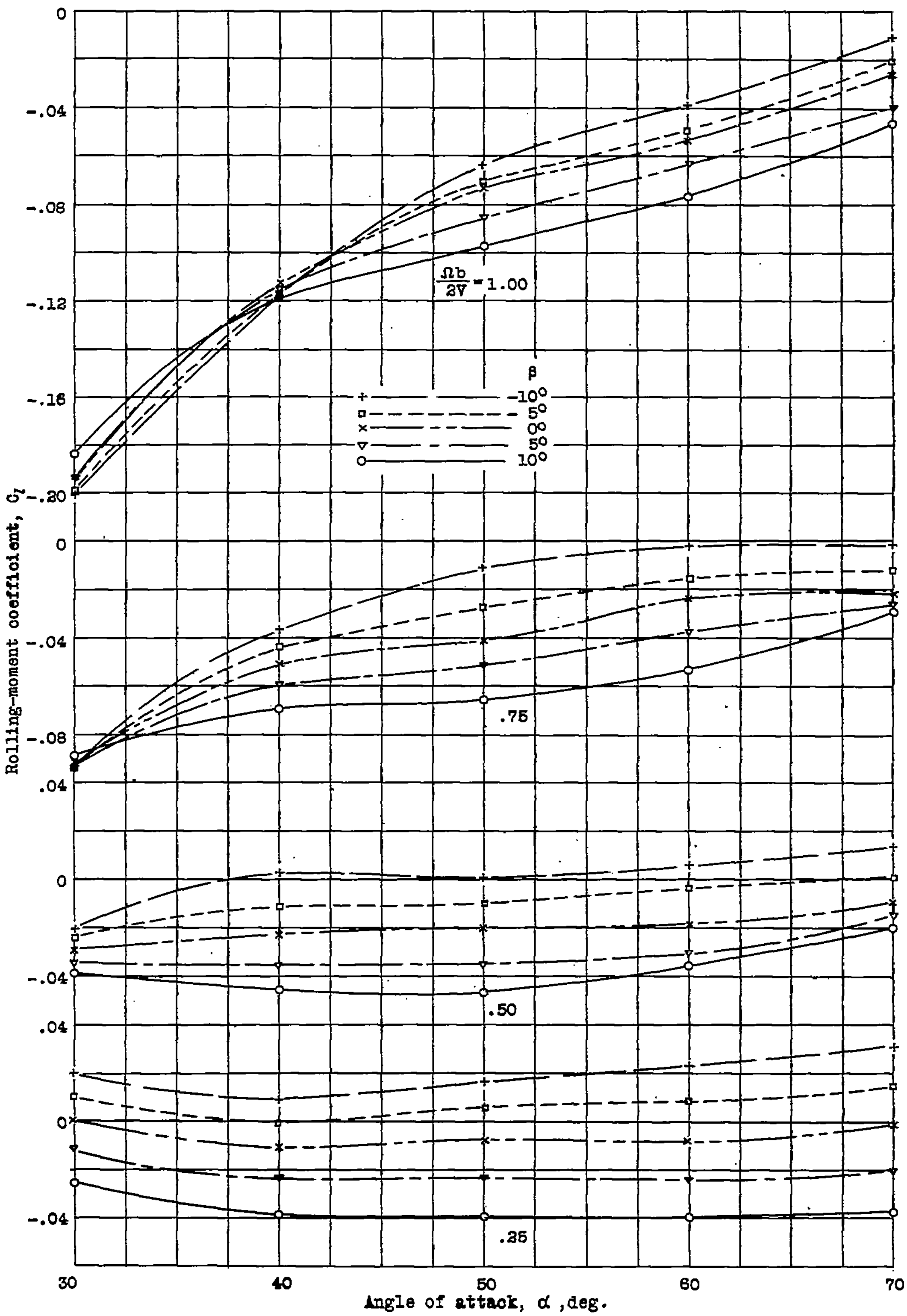


Figure 9a.- Variation of rolling-moment coefficient C_l (body axes) with angle of attack; rectangular wing, rounded tips.

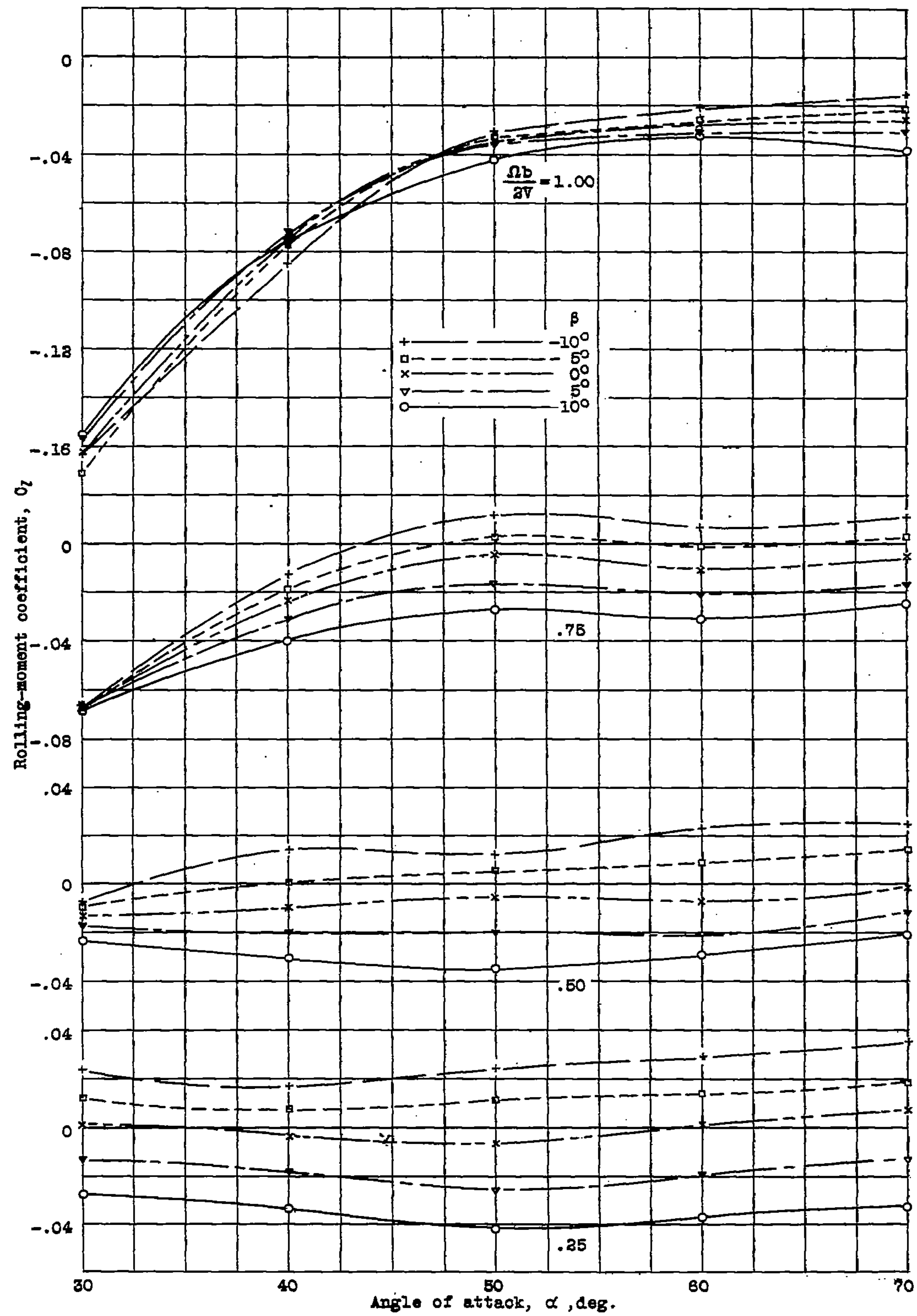


Figure 9b.- Variation of rolling-moment coefficient C_l (body axes) with angle of attack; 5:2 tapered wing, rounded tips.

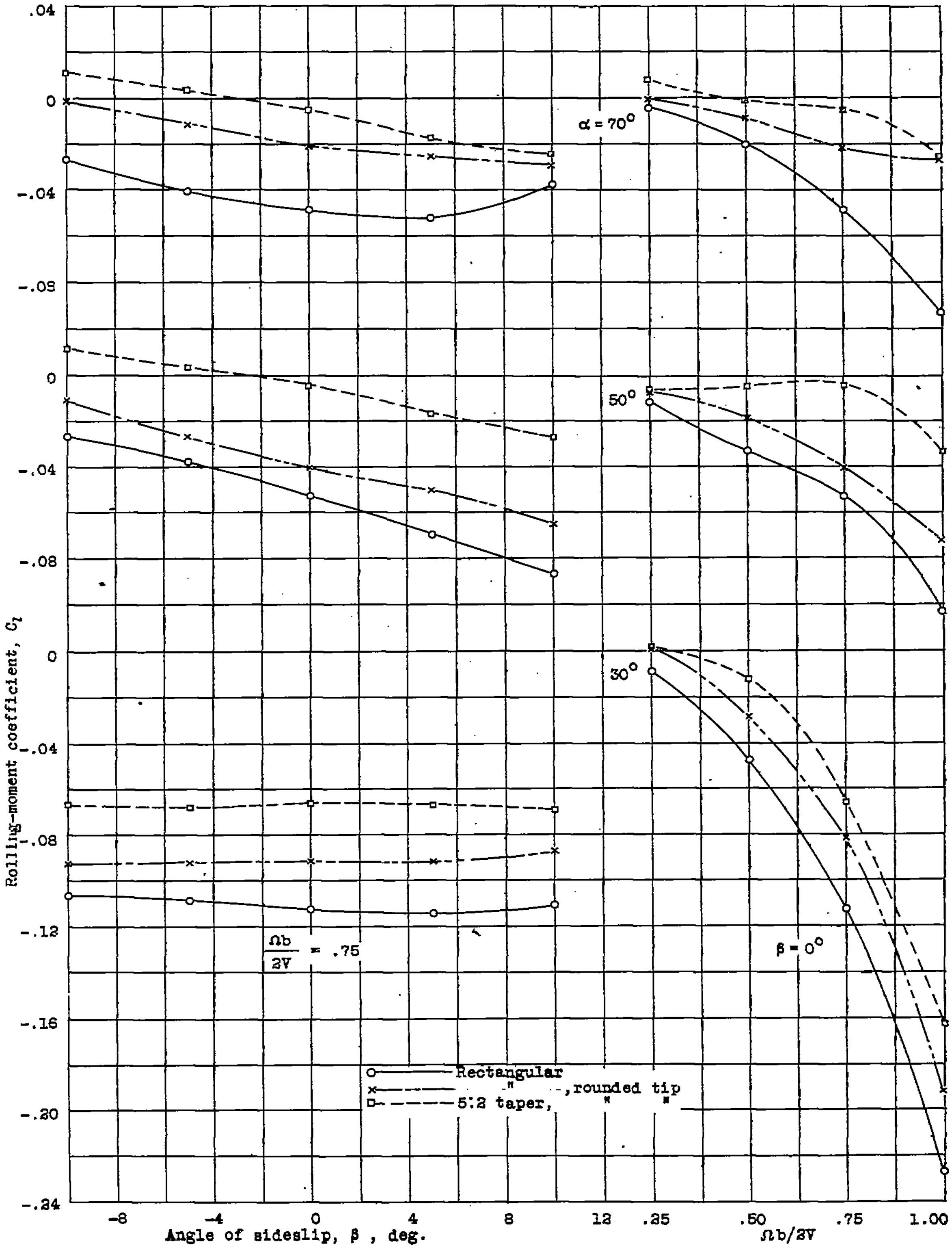


Figure 10.- Variation of rolling-moment coefficient C_l (body axes) with angle of sideslip and $\Omega b/2V$.

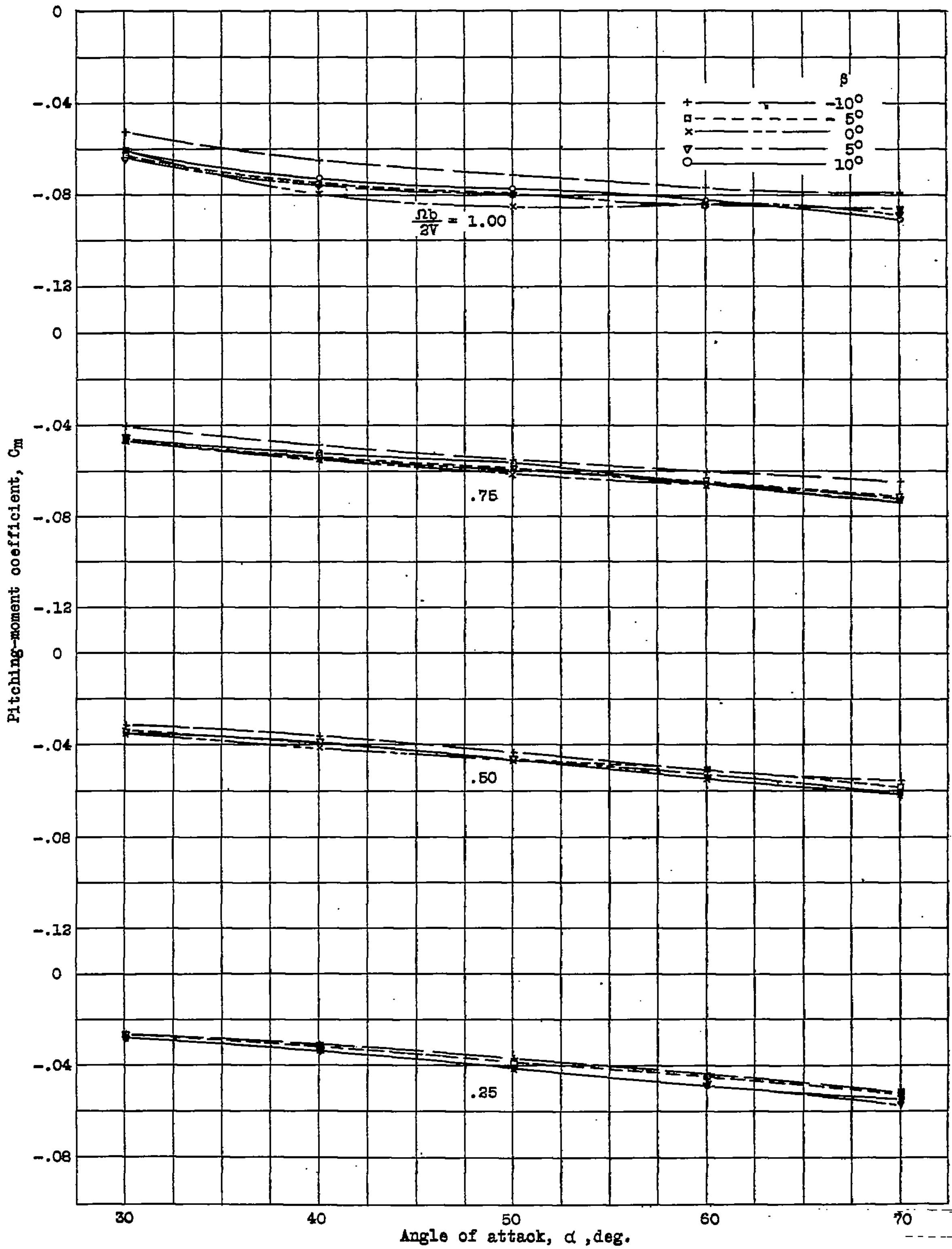


Figure 11a.- Variation of pitching-moment coefficient C_m (body axes) with angle of attack; rectangular wing, rounded tips.

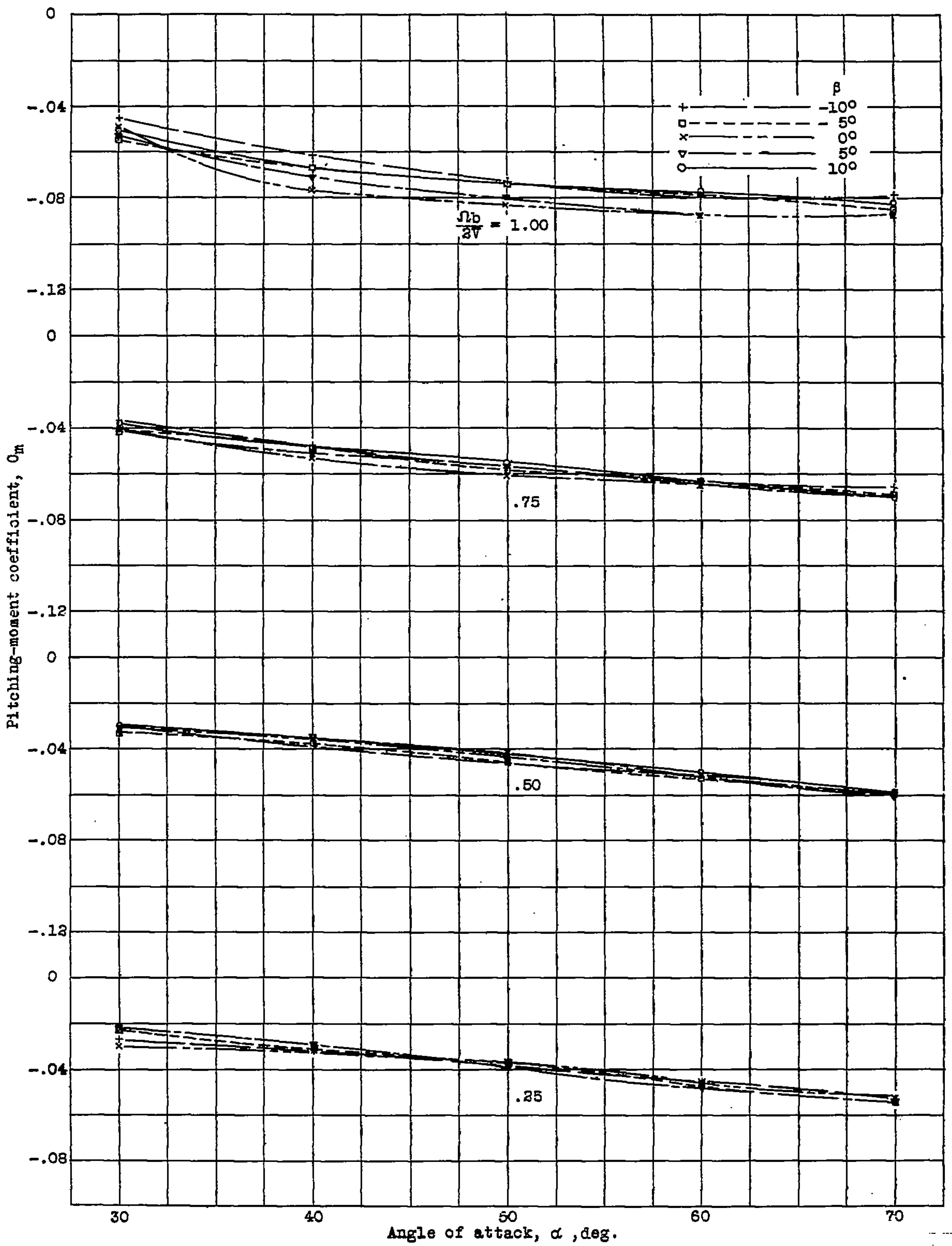


Figure 11b.- Variation of pitching-moment coefficient C_m (body axes) with angle of attack; 5:2 tapered wing; rounded tip.

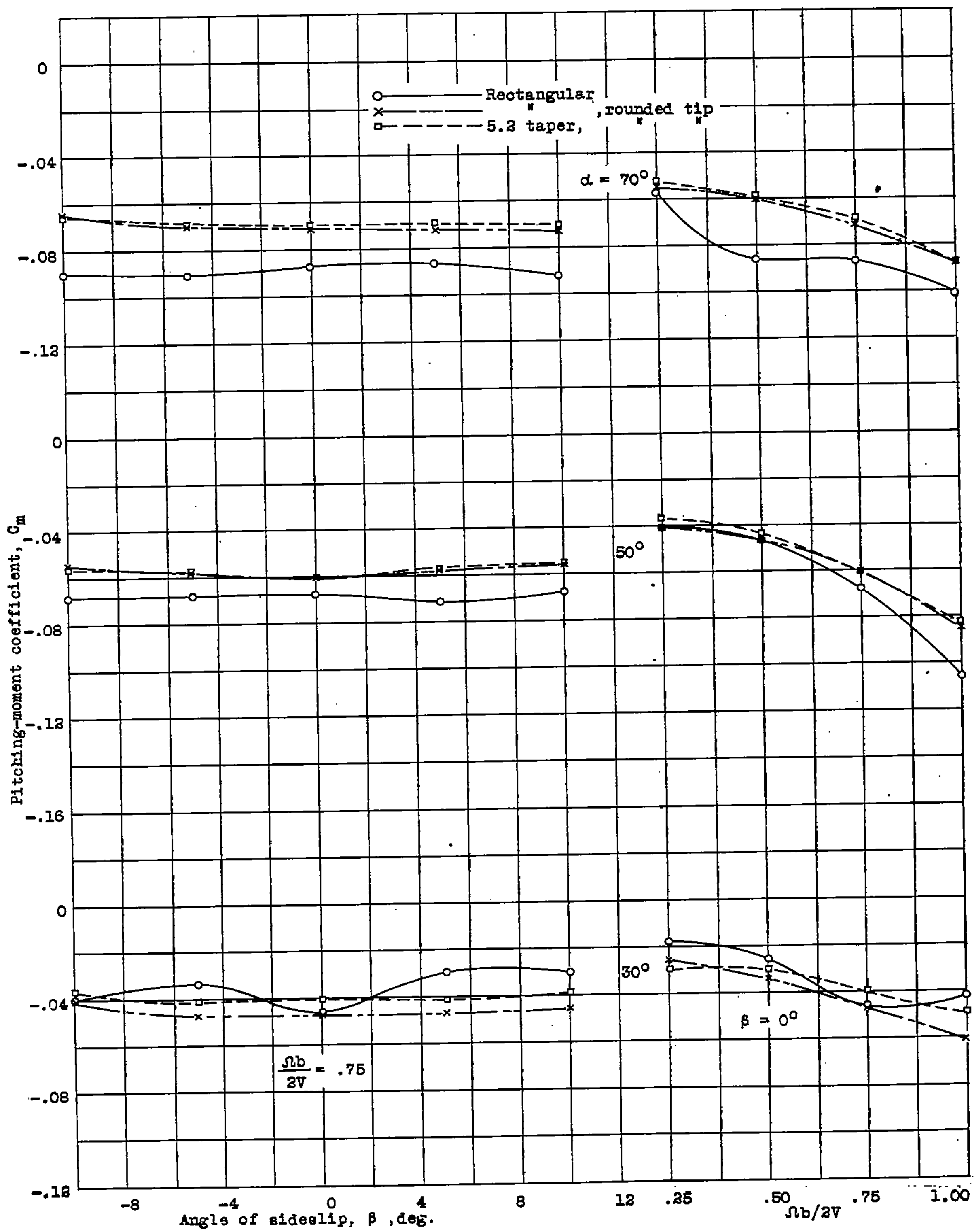


Figure 12.- Variation of pitching-moment coefficient C_m(body axes) with angle of sideslip and $\Omega b/2V$.

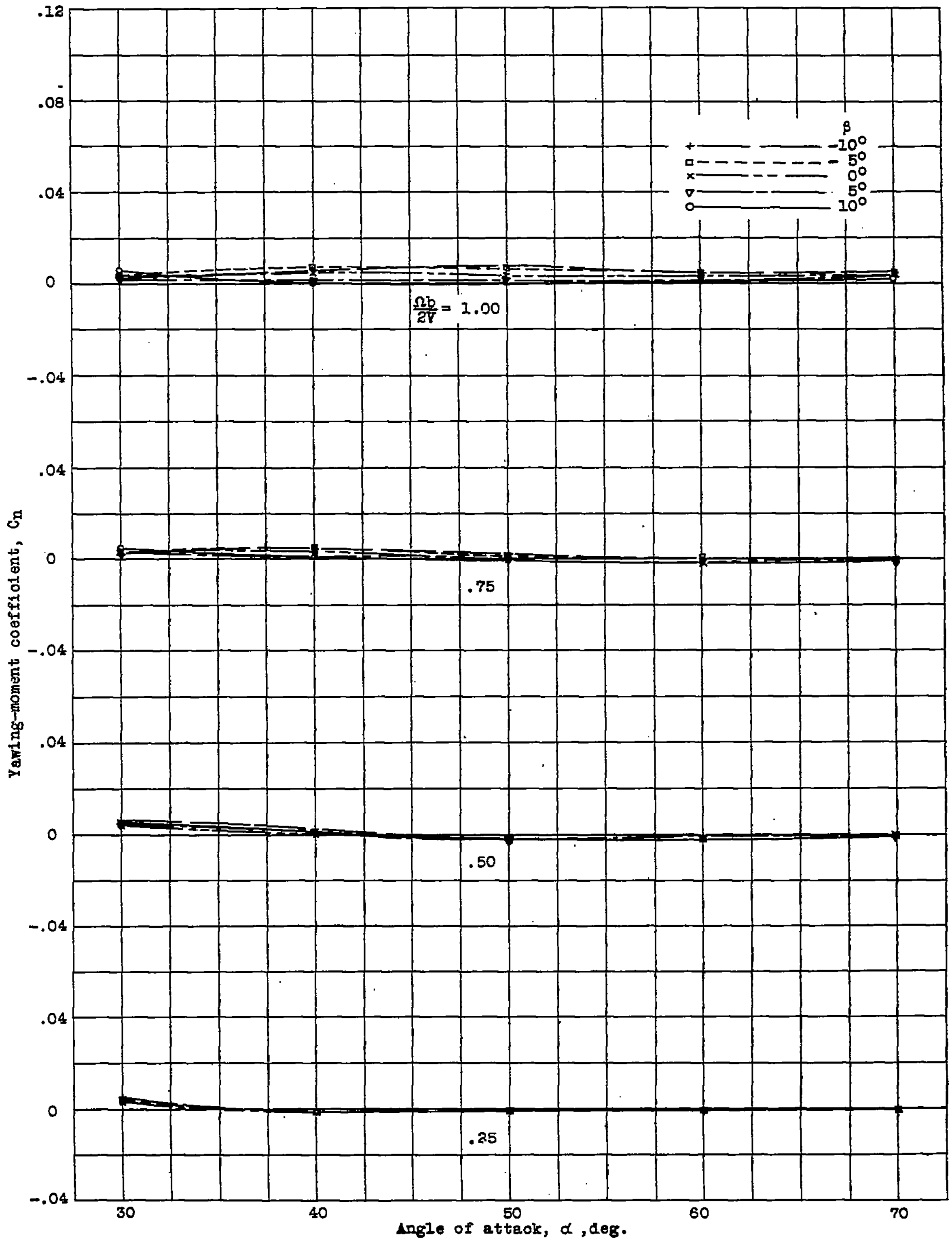


Figure 13a.- Variation of yawing-moment coefficient C_n (body axes) with angle of attack; rectangular wing, rounded tips.

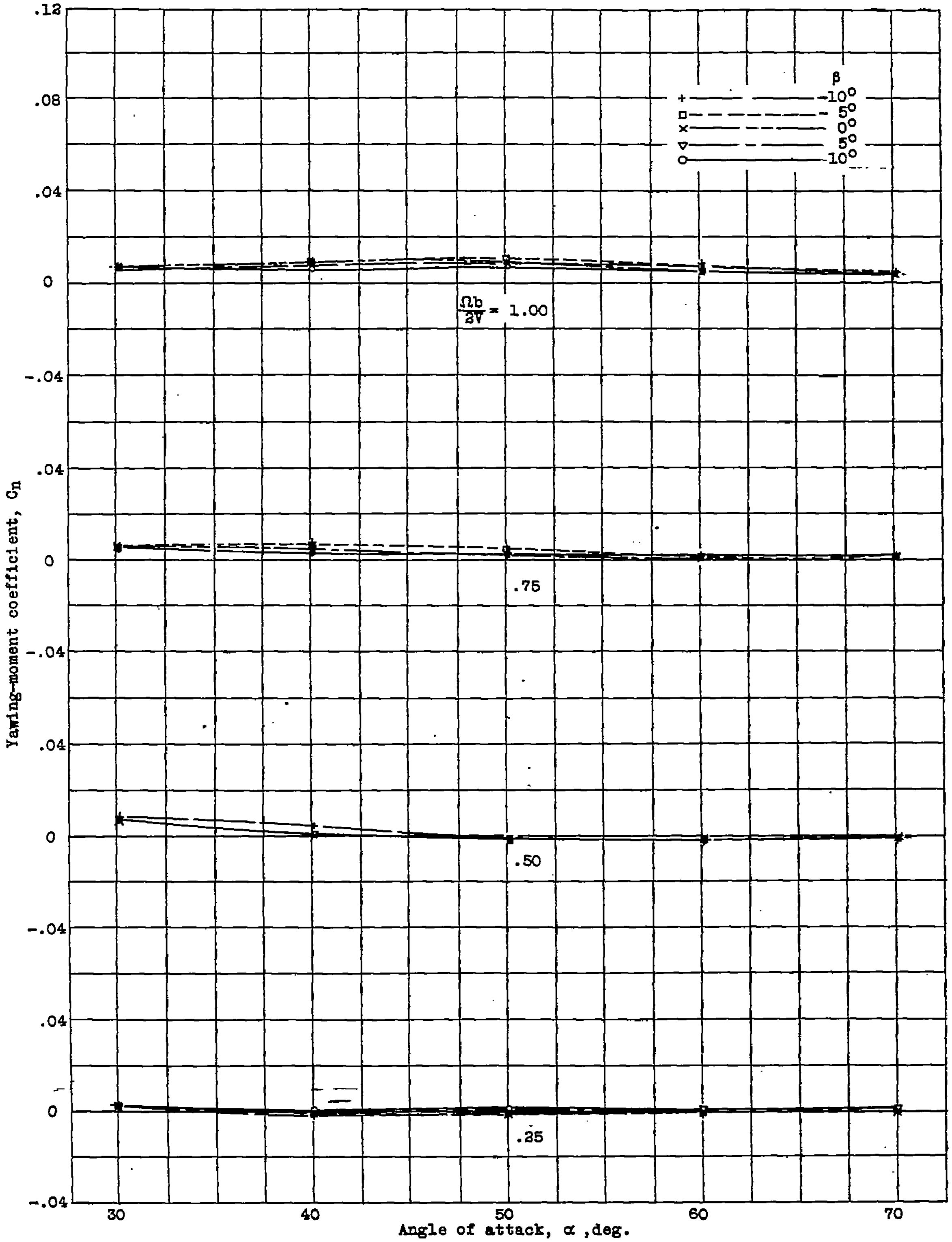


Figure 13b.- Variation of yawing-moment coefficient C_n (body axes) with angle of attack; 5:2 tapered wing, rounded tips.

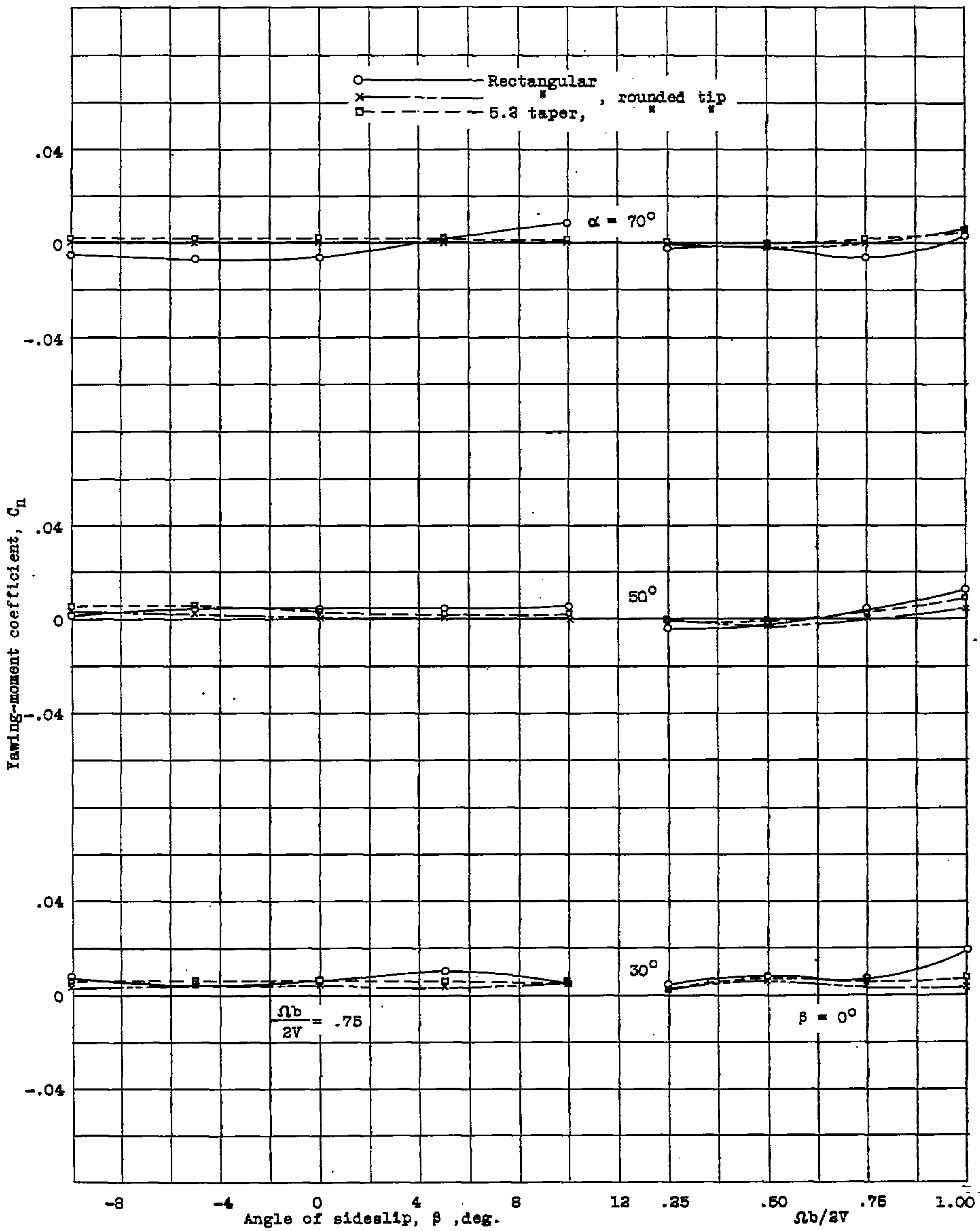
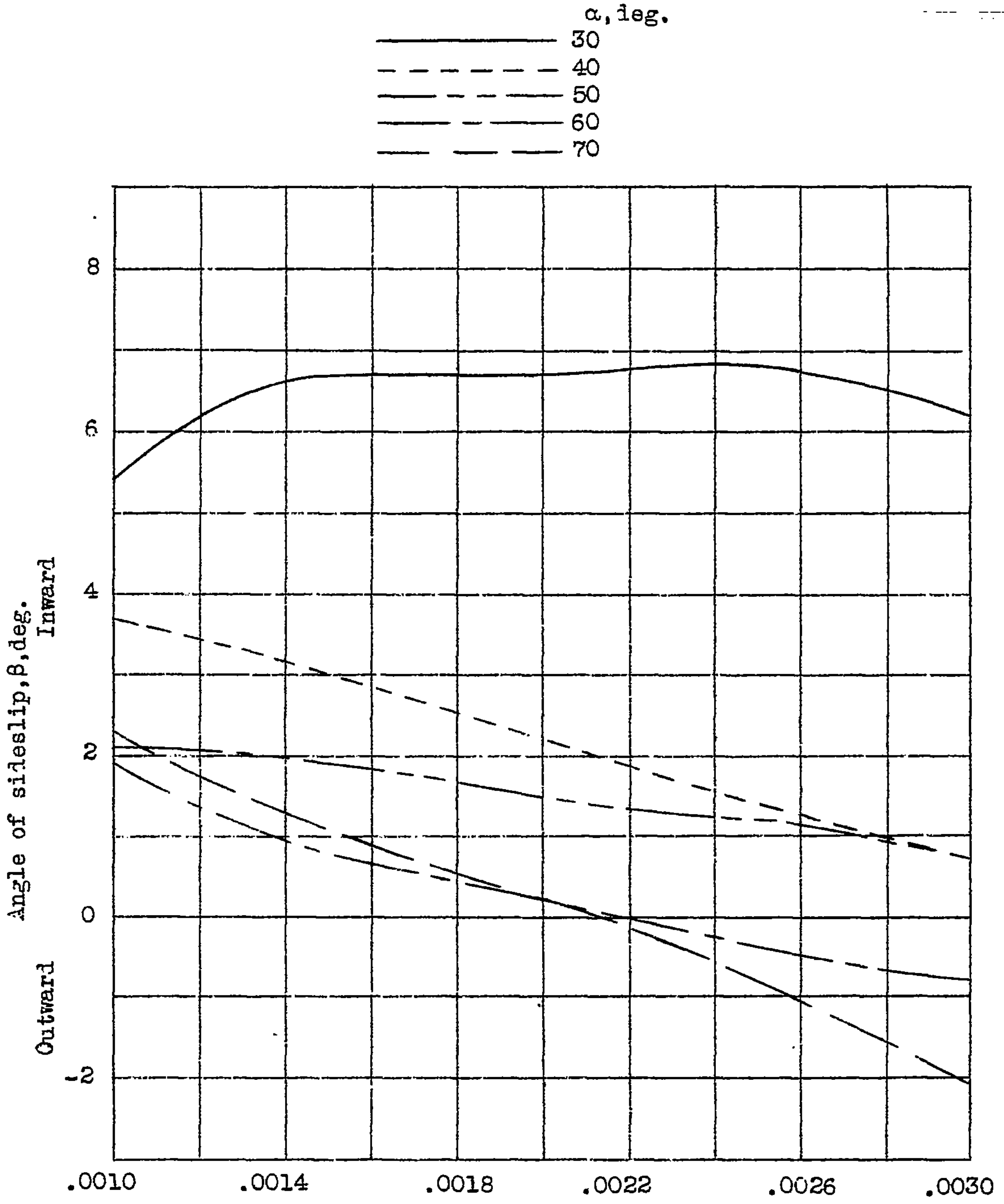


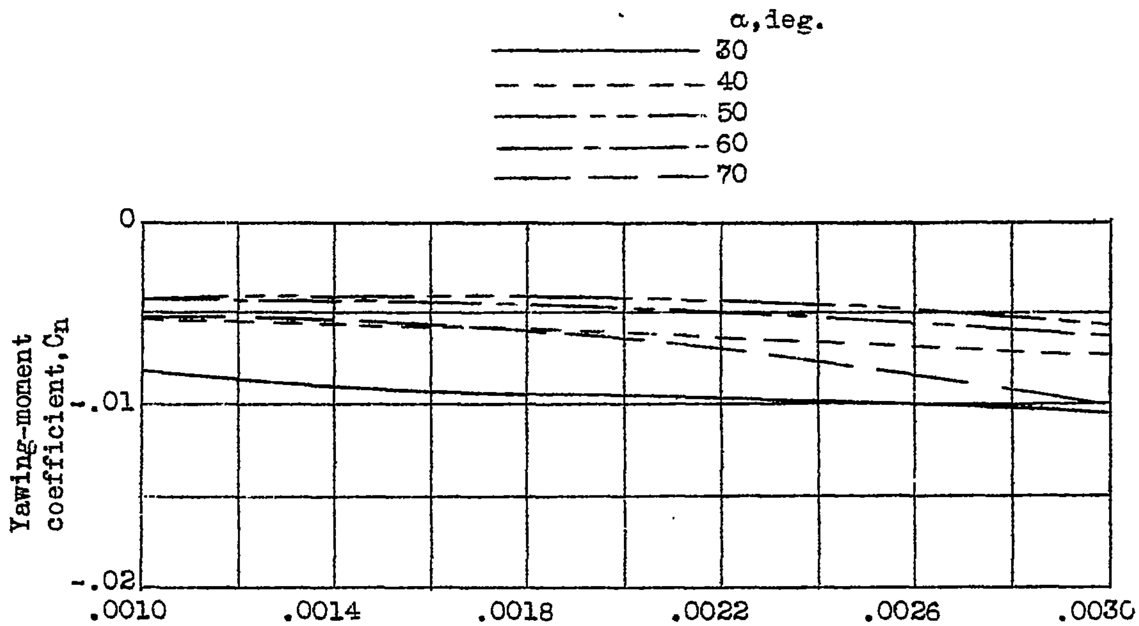
Figure 14.- Variation of yawing-moment coefficient C_n(body axes) with angle of sideslip and $\Omega b/2V$.



Slope of assumed pitching-moment-coefficient curve, $\frac{-C_m}{\alpha - 20^\circ}$

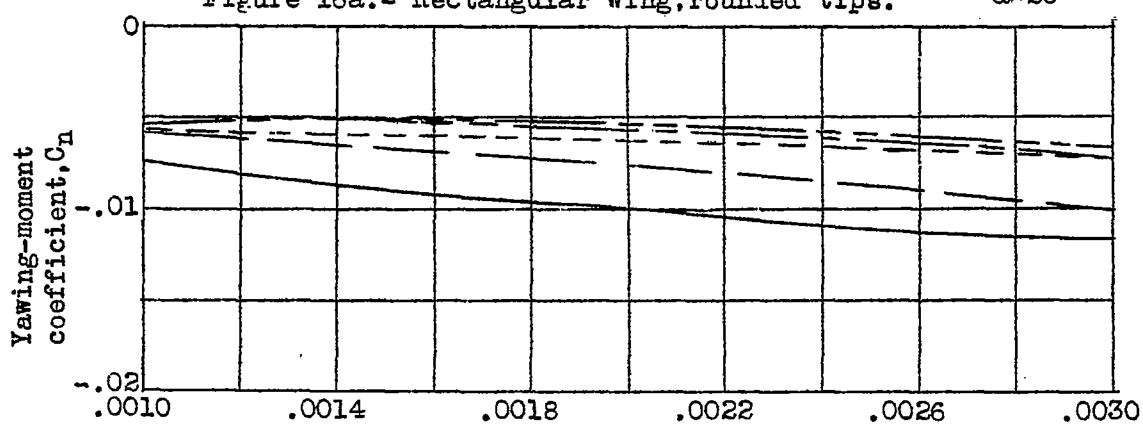
Figure 15b.- Effect of pitching-moment coefficient upon sideslip necessary for equilibrium in a spin; 5:2 tapered wing, rounded tips.

$\mu = 5$ $C_L = C_{X''}$ $\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 1.0$ $\frac{b^2}{k_Z^2 - k_X^2} = 80$



Slope of assumed pitching-moment-coefficient curve, $\frac{-C_m}{\alpha-20^\circ}$

Figure 16a.- Rectangular wing, rounded tips.



Slope of assumed pitching -moment-coefficient curve, $\frac{-C_m}{\alpha-20^\circ}$

Figure 16b.- 5:2 tapered wing, rounded tips.

Figure 16a, 16b.- Effect of pitching-moment coefficient upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin.

$\mu = 5$ $C_L = C_{X''}$ $\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 1.0$ $\frac{b^2}{k_Z^2 - k_X^2} = 80$

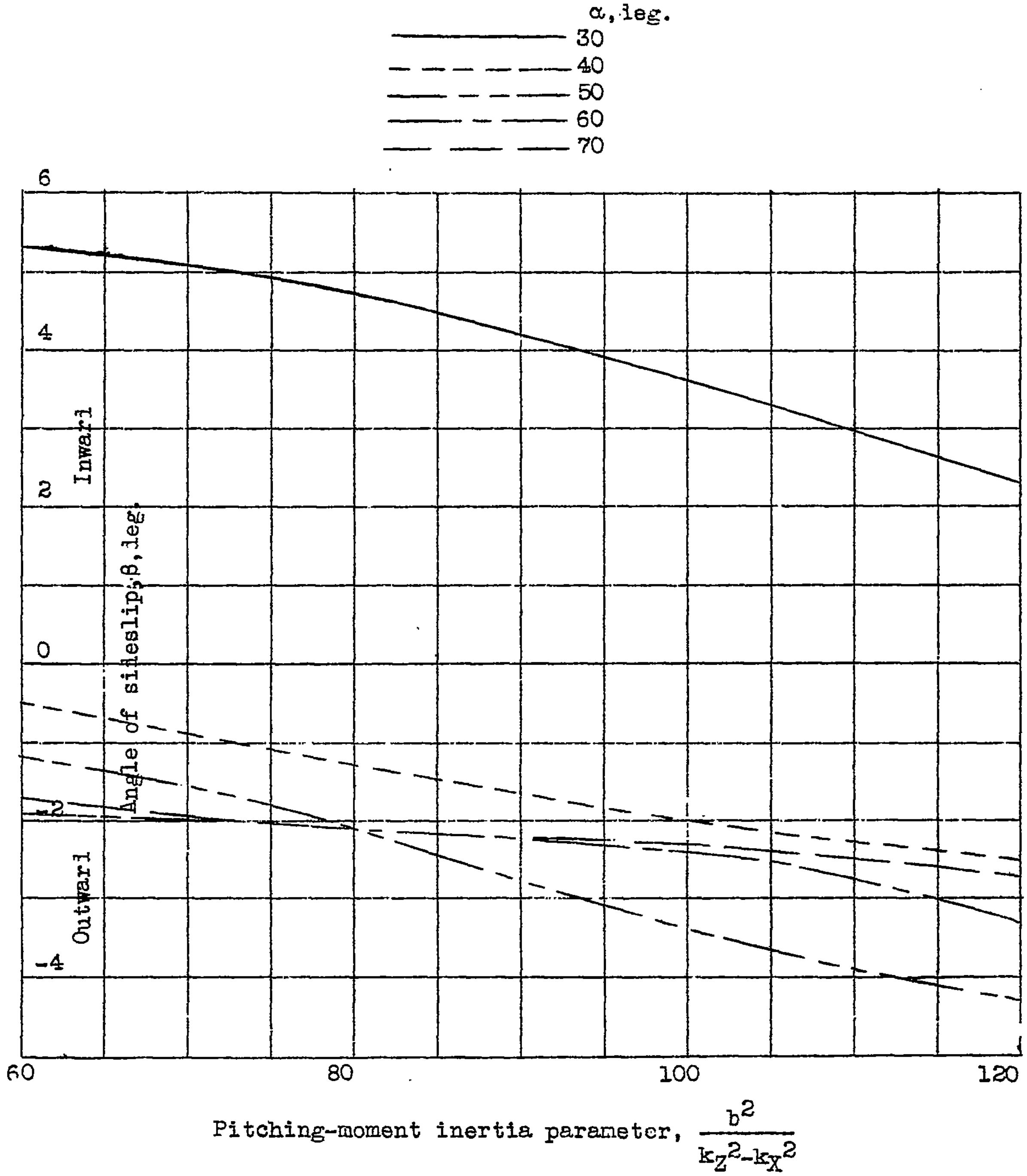


Figure 17a.- Effect of pitching-moment inertia parameter upon sideslip necessary for equilibrium in a spin; rectangular wing, rounded tips.

$\mu = 5$ $C_L = C_X''$ $C_m = -0.0020(\alpha - 20^\circ)$ $\frac{k_Z^2-k_Y^2}{k_Z^2-k_X^2} = 1.0$

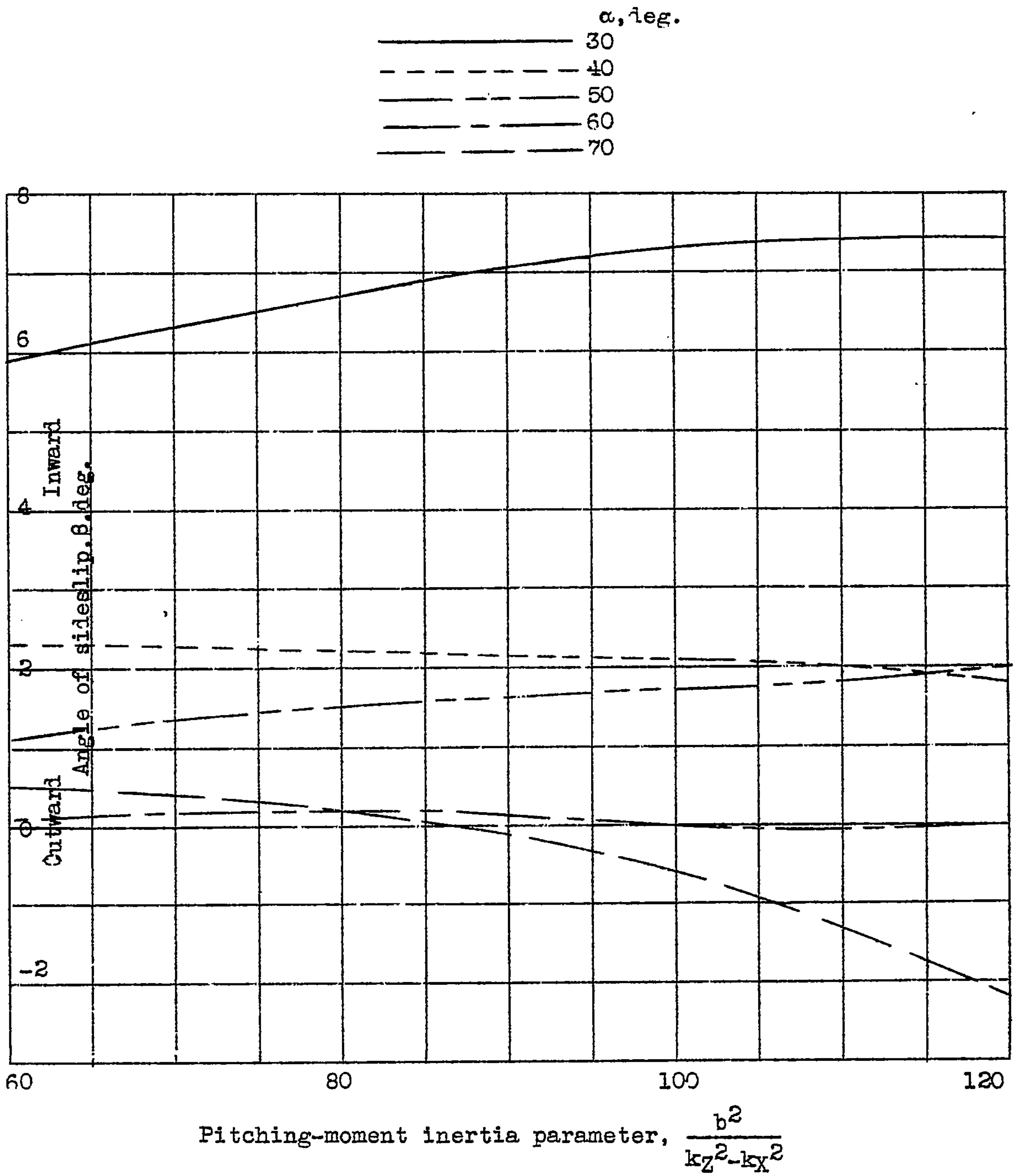


Figure 17b.- Effect of pitching-moment inertia parameter upon sideslip necessary for equilibrium in a spin; 5:2 tapered wing, rounded tips.

$\mu = 5$ $C_L = C_X''$ $C_m = -0.0020(\alpha - 20^\circ)$ $\frac{k_Z{}^2 - k_Y{}^2}{k_Z{}^2 - k_X{}^2} = 1.0$

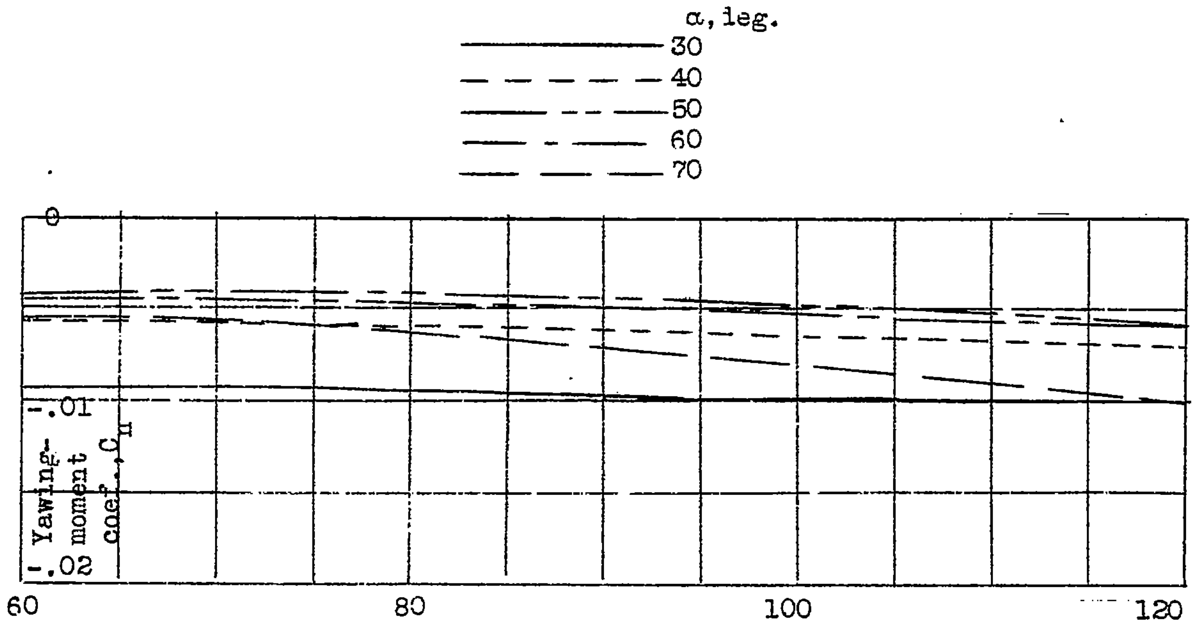


Figure 18a.- Rectangular wing, rounded tips.

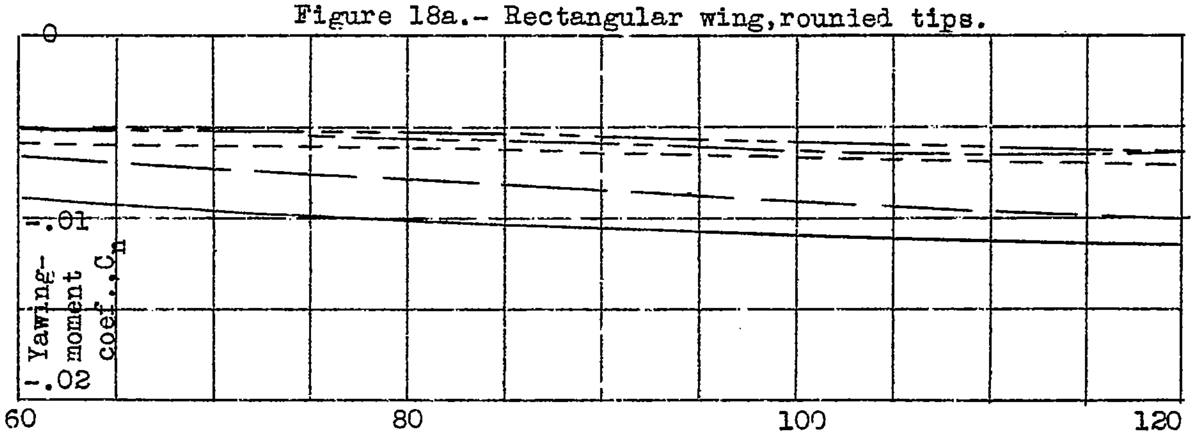


Figure 18b.- 5:2 tapered wing, rounded tips.

Figure 18a, 18b.- Effect of pitching-moment inertia parameter upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin,

$\mu = 5$ $C_L = C_{X''}$ $C_m = -0.0020(\alpha - 20^\circ)$ $\frac{k_Z^2-k_Y^2}{k_Z^2-k_X^2} = 1.0$

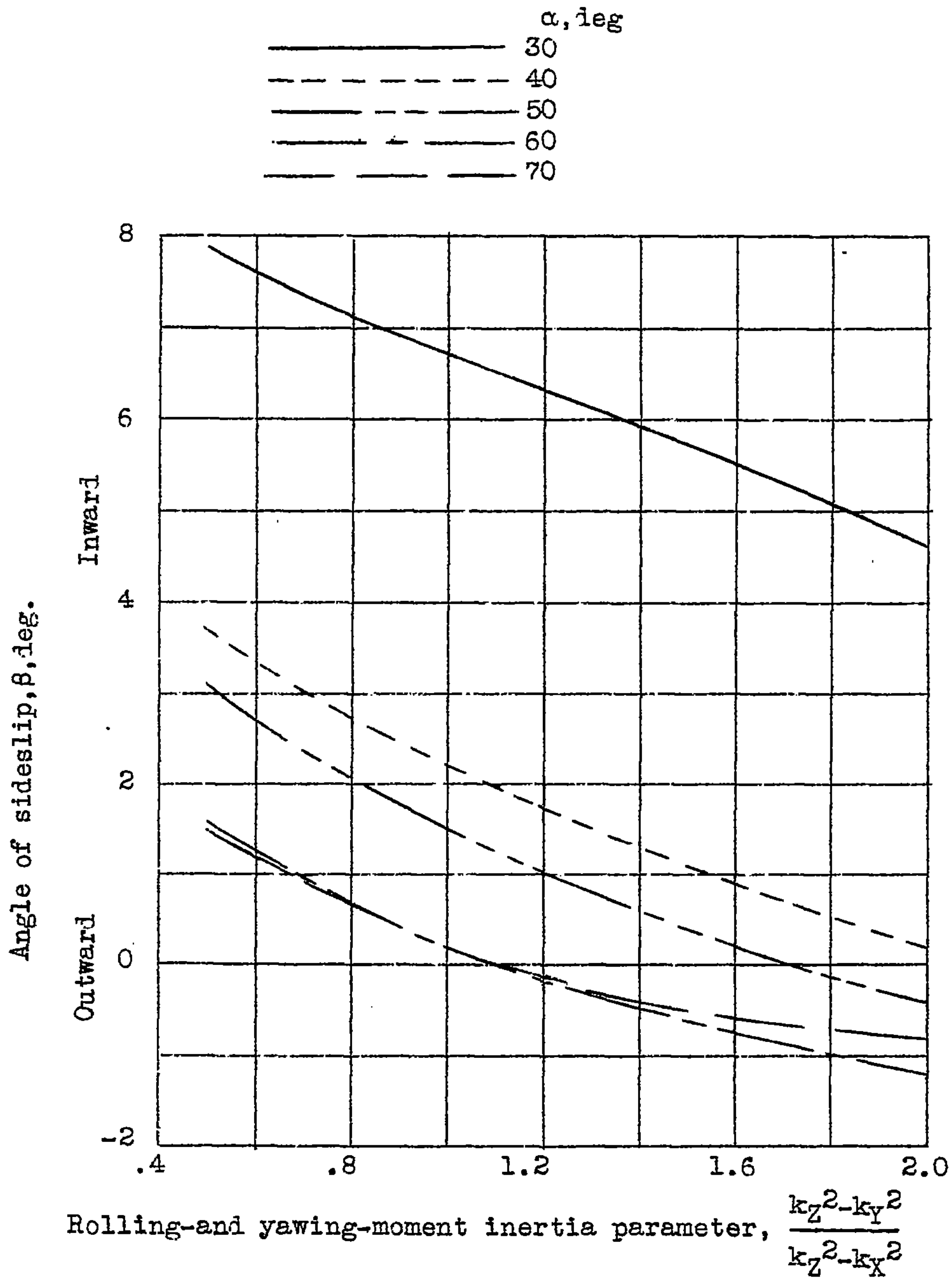


Figure 19b.- Effect of rolling-and yawing-moment inertia parameter upon sideslip necessary for equilibrium in a spin; 5:2 tapered wing, rounded tips.

$\mu = 5$ $C_L = C_X''$ $C_m = -0.0020(\alpha - 20^\circ)$ $\frac{b^2}{k_Z^2-K_X^2} = 80$

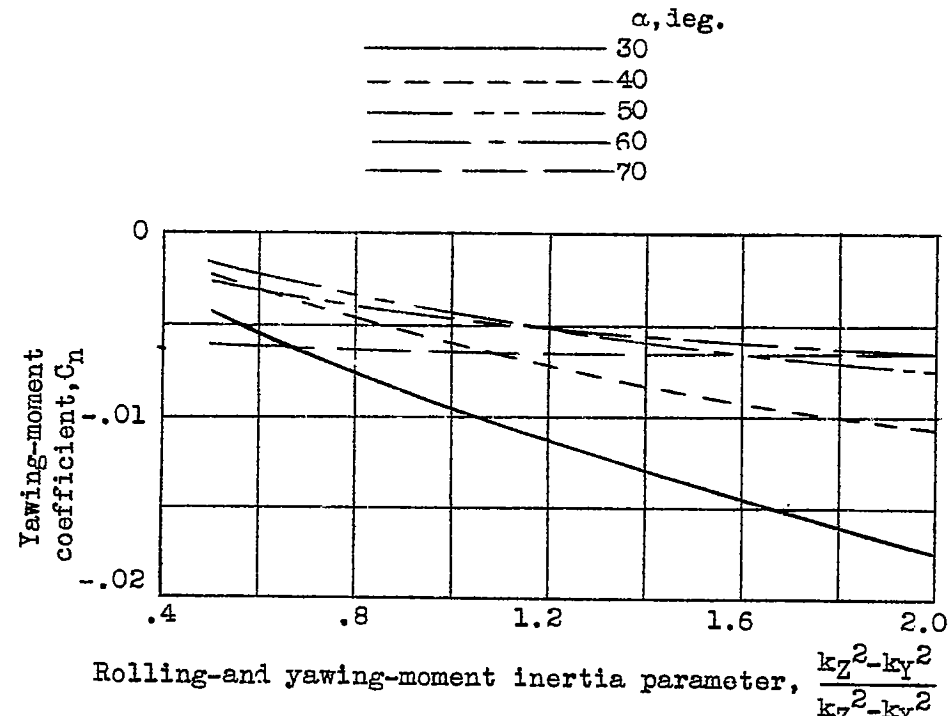


Figure 20a.- Rectangular wing, rounded tips.

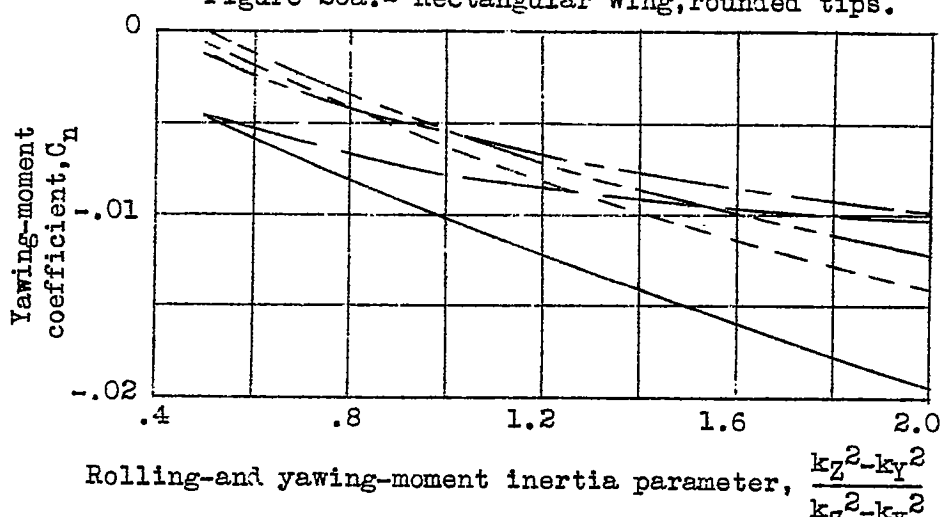


Figure 20b.- 5:2 tapered wing, rounded tips.

Figure. 20a,20b.- Effect of rolling-and yawing-moment inertia parameter upon yawing-moment coefficient that must be supplied by parts other than the wing for equilibrium in a spin.

$\mu = 5$ $C_L = C_X$" $C_m = -0.0020(\alpha - 20^\circ)$ $\frac{b^2}{k_Z^2-k_X^2} = 80$

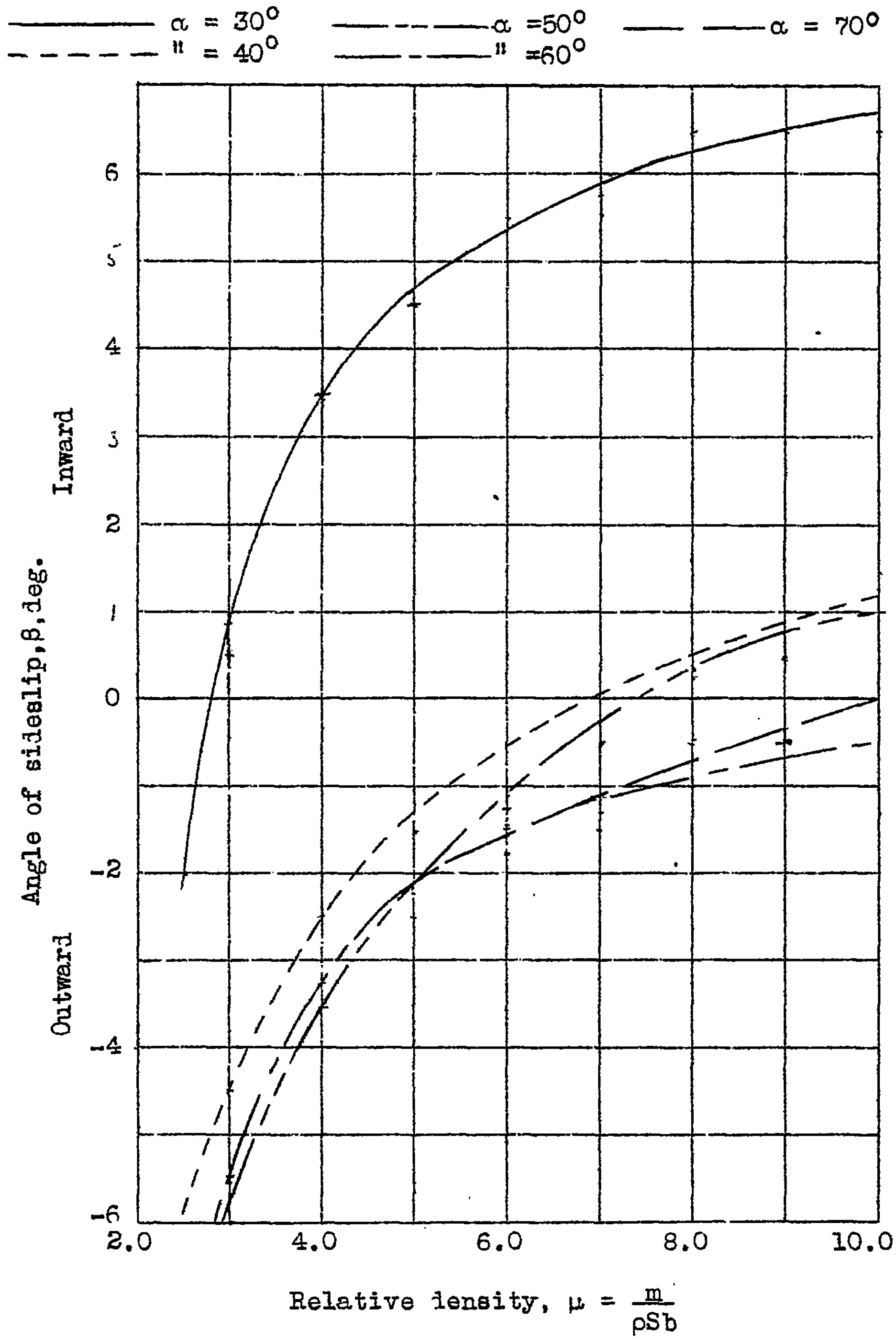


Figure 21a.- Effect of relative density of airplane upon sideslip necessary for equilibrium in a spin; rectangular wing, rounded tips.

$C_m = -0.0020(\alpha - 20°)$ $C_L = C_{X''}$ $\frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 1.0$ $\frac{b^2}{k_Z^2 - k_X^2} = 80$

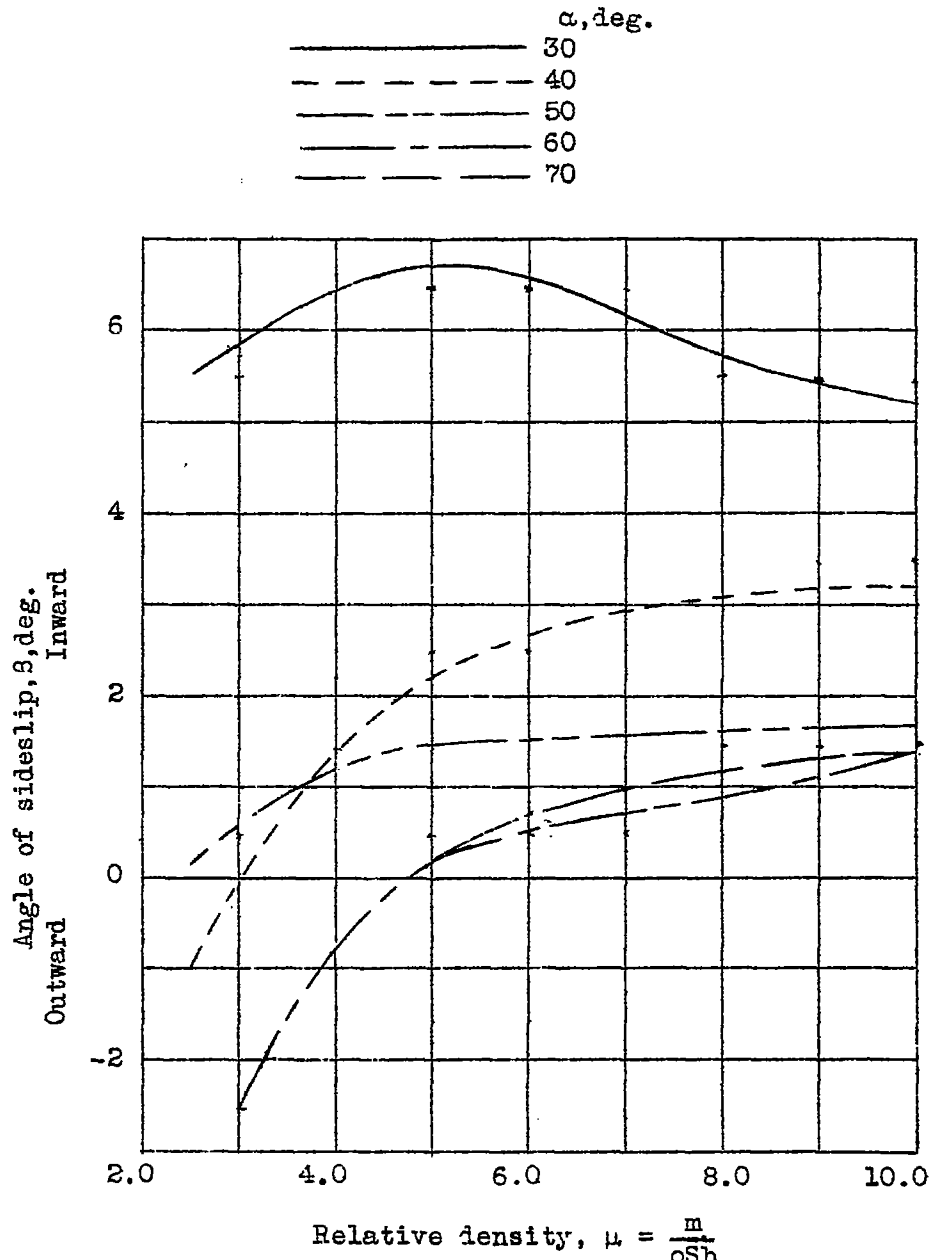


Figure 21b.- Effect of relative density of airplane upon sideslip necessary for equilibrium in a spin; 5:2 tapered wing, rounded tips.

$C_m = -0.0020(\alpha - 20^\circ)$ $\quad C_L = C_{X''}$ $\quad \frac{k_Z^2 - k_Y^2}{k_Z^2 - k_X^2} = 1.0$ $\quad \frac{b^2}{k_Z^2 - k_X^2} = 80$